GPS/INS uses Low-Cost MEMS IMU

A description of the design, operation, and test results of a miniature, low-cost, integrated GPS/inertial navigation system that uses commercial off-the-shelf Micro-Electro-Mechanical System (MEMS) accelerometers and gyroscopes. The MEMS inertial measurement unit (IMU) is packaged in a small size and provides the raw IMU data through a serial interface to a processor board where the inertial navigation solution and integrated GPS/inertial Kalman filter is generated.

The GPS/inertial software integration is performed using NAVSYS’ modular InterNav software product. This allows integration with different low-cost GPS chip sets or receivers and also allows the integrated GPS/inertial navigation solution to be embedded as an application on a customer’s host computer. This modular, object-oriented architecture facilitates integration of the miniature MEMS GPS/INS navigation system for embedded navigation applications and is designed to handle the large errors characteristic of a low-grade MEMS IMU.

Test results are presented showing the performance of the integrated MEMS GPS/inertial navigation system. Data is provided showing the position, velocity, and attitude accuracy when operating with GPS aiding and for periods where GPS dropout occurs and alternative navigation update sources are used to bound the MEMS inertial navigation error growth.

IMA Aircraft Improvements

Integrated Modular Avionics (IMA) is being suggested as the means by which new capabilities can be deployed on aircraft at an affordable cost. RTCA SC-200 is presently considering the guidance document for IMA. All of the functionality that IMA offers can be achieved through a conventional federated architecture; however, the cost, size, and weight penalties of the federated solution make it economically infeasible. IMA is seen as the way forward. It is assuming greater importance as the the aircraft industry transitions to Commercial-Off-The-Shelf (COTS) technology with its attendant obsolescence and reliability concerns. IMA may be one of the most cost-effective ways by which rapid obsolescence can be managed. Ironically, this move to COTS is also the greatest threat to IMA systems.

IMA achieves reductions in size, cost, and weight by providing a set of flexible hardware and software resources that can be statically or dynamically mapped to a set of required avionics functional capabilities. This introduces a number of new complexities such as mixed criticalities and reconfiguration. We do not address these issues herein. Rather, we discuss the mechanisms by which electronics degrades and how a classical safety assessment of a reconfigurable IMA system can be nullified by this degradation.

We argue that, with the advent of COTS, it is no longer justifiable to consider that electronics has an effectively constant failure rate. Physical considerations suggest that electronics failure occurs when environmental and operating stress causes the accumulation of damage to the underlying structures to exceed the threshold strength of the constituent materials and interfaces. Finally, we suggest how finite-life electronics effects may be mitigated.

The Rolling Radar

In the search for a better rotating radar, a self-supporting array that rolls like a wheel can improve mechanical reliability and return higher-definition target resolution [1]. The Rolling Radar concept evolved from the need to design and build a large rotating 3D radar as an alternative to multifaceted fixed radar installations, or large, expensive rotating radar systems. However, the physical act of rotating massive structures weighing many tons introduces a host of load bearing and other mechanical reliability problems. An alternative design needed to be conceptualized.

The new concept places the radar array inside a large wheel attached to an axle. A smaller wheel affixed to the axle’s other end provides support when both wheels simultaneously roll along electrified concentric rails in order to scan 360 degrees.

The array wheel propels itself via a simple gravity drive consisting of a magnetic carriage that rides an electromagnet around the inside circumference of the large array wheel. Displacement of its own weight causes the wheel (and the entire axle) to roll around the railed track with no visible external means of motion.

Satellite Data Collection & Forwarding Systems

A possible classification of satellites can be related to their capability to provide or not provide real-time services. Non-real-time systems store the information and forward it to destination later, usually by means of Low Earth Orbit (LEO) satellites. Nowadays, the main application of these systems is to small data exchange to/from remote sites where no other communication infrastructure is available, hence, covering a niche market. Low on-board memory storage capability and, moreover, low bit rate due to little bandwidth allocated for these systems do not allow us to collect and forward a considerable volume of data in the short visibility window of the satellite passage. New applications and services can be conceived through the deployment of new systems able to overcome the above-described limitations, while existing applications can be provided more cost-effectively. These aspects are addressed together with an experimental interactive system which allows huge data collection in W-band and for forwarding to the Internet.

Fiber-Optic Radar Calibration

A simple fiber-optic radar calibration target is described. Its operation is based on a wideband fiber, a laser transmitter that is directly modulated by the down-converted radar signal and an optical diode receiver recovering said signal. Further up-conversion having a common local oscillator with the first mixer ensures fidelity of the calibration return. Measured useful bandwidth exceeds 200 MHz and practically any radar RF frequency can be handled when suitable mixers are employed. Amplifiers can be added to the down-converted path as desired to compensate for the fiber loss. Modulation and LO sweep provide easy ways of introducing artificial fluctuations and Doppler frequencies. Particularly pulsed radars are readily tested with the proposed scheme as no restrictions are posed by the radar’s TR-switch delays.
GPS/INS uses Low-Cost MEMS IMU

Alison K. Brown
NAVSYS Corporation

ABSTRACT

A description of the design, operation, and test results of a miniature, low-cost, integrated GPS/inertial navigation system that uses commercial off-the-shelf Micro-Electro-Mechanical System (MEMS) accelerometers and gyroscopes. The MEMS inertial measurement unit (IMU) is packaged in a small size and provides the raw IMU data through a serial interface to a processor board where the inertial navigation solution and integrated GPS/inertial Kalman filter is generated.

The GPS/inertial software integration is performed using NAVSYS' modular InterNav software product. This allows integration with different low-cost GPS chip sets or receivers and also allows the integrated GPS/inertial navigation solution to be embedded as an application on a customer's host computer. This modular object-oriented architecture facilitates integration of the miniature MEMS GPS/INS navigation system for embedded navigation applications and is designed to handle the large errors characteristic of a low-grade MEMS IMU.

Test results are presented showing the performance of the integrated MEMS GPS/inertial navigation system. Data is provided showing the position, velocity, and attitude accuracy when operating with GPS aiding and also for periods where GPS dropouts occur and alternative navigation update sources are used to bound the MEMS inertial navigation error growth.

INTRODUCTION

The advent of low-cost, MEMS accelerometers and gyroscopes offers the opportunity for applying inertial navigation for a wide variety of new applications. This includes navigation and guidance of low-cost, small unmanned air vehicles (UAVs) or unmanned ground vehicles (UGVs) such as shown in Figures 1 and 2. While the principles of inertial navigation are well-understood, the challenge, when working with the current generation of low-cost MEMS instruments, is to develop a robust navigation capability that can deal with the large instrument errors experienced with these low-grade accelerometers and gyroscopes. The software product described in this paper, InterNav, was developed to include this capability. This paper describes the approach taken for providing inertial navigation with low-grade MEMS

Fig. 1. Silver Fox UAV [1]

Fig. 2. Unmanned Ground Vehicle [2]
Table 1. IMU Gyroscope and Accelerometer Parameter Comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td></td>
<td>33 cu in</td>
<td>1.6 cu in</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>32 oz</td>
<td>0.7 oz</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>8 w</td>
<td>0.7 w</td>
</tr>
</tbody>
</table>

Gyrosopes

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Range</td>
<td>±1/2°</td>
<td>1000</td>
<td>300</td>
</tr>
<tr>
<td>Scale factor accuracy (1 σ)</td>
<td>ppm</td>
<td>150</td>
<td>25000</td>
</tr>
<tr>
<td>Scale factor linearity 1 σ to ± 800 ‰</td>
<td>ppm</td>
<td>150</td>
<td>N/A</td>
</tr>
<tr>
<td>Bias (1 σ)</td>
<td>°/hour</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>Axis alignment stability (1 σ)</td>
<td>µrad</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>Axis alignment stability, non-orthogonality (1 σ)</td>
<td>µrad</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Output noise (1 σ of 10,000 samples)</td>
<td>µrad</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Angular random walk max.</td>
<td>°/Rt-hr</td>
<td>0.1</td>
<td>3</td>
</tr>
</tbody>
</table>

Accelerometers

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Range</td>
<td>±g</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Scale factor accuracy (1 σ)</td>
<td>ppm</td>
<td>300</td>
<td>25000</td>
</tr>
<tr>
<td>Scale factor linearity (1 σ)</td>
<td>ppm</td>
<td>500</td>
<td>N/A</td>
</tr>
<tr>
<td>Bias (1 σ)</td>
<td>mg</td>
<td>1.0</td>
<td>15000</td>
</tr>
<tr>
<td>Axis alignment stability (1 σ)</td>
<td>µrad</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>Axis alignment stability, non-orthogonality (1 σ)</td>
<td>µrad</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Output noise (1 σ of 10,000 samples)</td>
<td>m/s</td>
<td>0.0024</td>
<td>0.0003</td>
</tr>
<tr>
<td>Velocity random walk</td>
<td>(µg/°/Hz)</td>
<td>150</td>
<td>400</td>
</tr>
</tbody>
</table>

1. Accelerometer includes filtering in sampled signal

Instruments and presents initial test results showing the type of navigation performance that can be expected using current generation MEMS devices.

**COMPARISON OF INERTIAL MEASUREMENT UNITS AND INSTRUMENT PERFORMANCE**

In Table 1, a comparison of a commercial off-the-shelf (COTS) MEMS IMU and a low-cost COTS Ring Laser Gyro (RLG) IMU is shown. The RLG IMU used for the comparison is the HG1700 produced by Honeywell (see Figure 3). This is available as a commercial unit and has been integrated into a number of different GPS/inertial products produced by NAVSYS [3, 4]. The MEMS IMU used for the comparison is the Crista IMU produced by Cloud Cap Technology (see Figure 4). This is built using a triad of Analog Devices accelerometers [5] and gyroscopes [6]. As seen from the performance figures in Table 1, the instruments used by the Crista IMU, while significantly smaller, lower-cost, and lower power, are almost a factor of 100 times less accurate than the HG1700 instruments. While future MEMS technologies promise to provide improved performance levels, approaching those of the HG1700 instruments, the challenge today for low cost navigation applications is to design an integrated system that can perform inertial navigation using these existing low grade MEMS instruments.

**INTERNAV SOFTWARE**

The MEMS inertial navigation integration and testing was performed using NAVSYS' InterNav integrated GPS/inertial software product [9]. InterNav includes the inertial navigation and Kalman filter functions used to combine inertial measurement unit raw data from the gyroscopes and accelerometers (Δθ, ΔV) with other sensor data to provide an integrated inertial navigation solution. The software includes the functions illustrated in Figure 5. The inertial measurements are integrated using a quaternion integration algorithm to
propagate the inertial states. Periodically, updates are performed to these states to calibrate the inertial state errors and instruments. A Kalman filter is used to perform these updates.

The InterNav software includes different Kalman filter configurations which are designed to perform both basic alignment of the inertial states, calibration of the inertial errors, and advanced functions to facilitate integration with a wide variety of different aiding sources of data. The basic InterNav filter states are shown in Table 2 [10]. To align the inertial navigation states, updates are required to observe the initial inertial error state. This is accomplished using a rough alignment mode of operation prior to transitioning to the Kalman filter fine alignment mode. In the rough alignment mode, the initial position, velocity, attitude, and rough calibration parameters for the inertial instruments are set. In the fine alignment mode, the filter calculates the best estimate

Table 2. Basic InterNav Kalman Filter Navigation States

<table>
<thead>
<tr>
<th>State</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Position Error (navigation frame)</td>
</tr>
<tr>
<td>4-6</td>
<td>Velocity Error (navigation frame)</td>
</tr>
<tr>
<td>7-9</td>
<td>Body Attitude Error (navigation frame)</td>
</tr>
<tr>
<td>10-12</td>
<td>Accelerometer bias error</td>
</tr>
<tr>
<td>13-15</td>
<td>Gyro bias error</td>
</tr>
<tr>
<td>16</td>
<td>GPS Clock bias error</td>
</tr>
<tr>
<td>17</td>
<td>GPS Clock frequency error</td>
</tr>
<tr>
<td>18-26</td>
<td>Accelerometer misalignment &amp; scale factor error</td>
</tr>
<tr>
<td>27-32</td>
<td>Gyro misalignment &amp; scale factor error</td>
</tr>
</tbody>
</table>
for these parameters using measurement updates from a GPS receiver or other source of aiding information.

The InterNav software is designed to accept inertial navigation updates from a variety of different sources as illustrated in Figure 19. For the purposes of the MEMS IMU performance testing, we used a GPS receiver as the sensor-aiding source. A discussion of how the different sensor inputs can be applied to aid the MEMS inertial navigation solution in the event of GPS dropouts is included in this paper.

**GPS AIDED MEMS IMU FIELD TEST RESULTS**

To test the MEMS IMU, we installed it on the GI-Eye test fixture shown in Figure 6. This unit includes the HG1700 IMU, a Novatel OEM-4 GPS receiver and antenna, a camera used as
MEMS INERTIAL PERFORMANCE FOLLOWING GPS DROP-OUTS

Because of the poor quality of the MEMS inertial instruments, the navigation performance degrades extremely rapidly following loss of the GPS-aiding data. To demonstrate this, a GPS drop-out was forced (post-test) in the data and the errors on the free-inertial propagated solution was compared against the GPS "truth" solution. The error growth during the dropout period is illustrated in Figures 14 to 17. As can be seen, the position error grows very rapidly without the GPS aiding, exceeding 10 meters within 20 seconds of the start of the drop-out. To maintain navigation performance when GPS is not available, another source of aiding information is essential.

AIDING SOURCES DURING GPS DROP-OUTS

The alternative sources of aiding information that the InterNav software is designed to accept are illustrated in Figure 19 and described below.

Altimeter

The vertical error growth in the inertial solution can be bounded by the addition of a baro-altimeter. This provides a measure of the change in altitude which is used as an update by the InterNav software.

Dead-Reckoning

InterNav will accept updates from dead reckoning sensors that can provide speed and heading information. An example of this type of back-up mode would be using a digital magnetic compass integrated with speed data either from an odometer (e.g., in a ground vehicle) or air speed indicator for (e.g., in an air vehicle). Applying these updates limits the inertial
navigation error drift rates to the accuracy of the aiding data source.

**Video Sensor**

InterNav is designed to accept updates of position offsets and relative motion updates using image processing functions operating on video input data [11, 12]. A model generation approach is used to track the motion of objects in images and also observe the inertial derived position offset from reference landmarks, as illustrated in Figure 18. These video updates can also be used to provide position updates and velocity updates to bound the inertial error growth during GPS drop-outs.

Communication TOA Updates

InterNav is designed to accept time-of-arrival (TOA) updates when they are available from a communications link. As an example, Link-16 provides TOA information that can be used to damp the inertial error growth following GPS drop-outs [13]. We are currently implementing TOA aiding within a Software Defined Radio (SDR) [14] that will provide
Fig. 19. InterNav Alternative Sensor Inputs

A similar function to perform aiding of the inertial solution following GPS drop-outs. In this mode of operation, participating units on the communications network that have access to the GPS signals. Detection can augment the performance of units without access to GPS by providing three TOA updates through their communication links.

CONCLUSION

In conclusion, our testing has shown that it is possible to perform inertial navigation using a low-grade, inexpensive MEMS IMU when GPS-aiding is available. The InterNav software includes the capability to observe and calibrate the MEMS inertial errors and can align the inertial navigation solution to provide the vehicle's pitch, roll, and heading in support of guidance and control operations.

The low accuracy of the MEMS inertial instruments means that the accuracy of the navigation solution degrades rapidly following loss of lock of the GPS signals. However, InterNav allows other types of navigation updates to be applied to bound the inertial error growth. The combination of GPS and back-up sensors for inertial aiding, as illustrated in Figure 19, allows inexpensive MEMS instruments to be used as a low-cost inertial navigation system.

REFERENCES

[2] IAI Unmanned Ground Vehicle,
  http://www.i-a-i.com/view.asp?type=view&PassageID=116&
  SubId=13&TopicID=1.

  Kinematic GPS-Inertial Navigation on a Tactical Fighter,
  Proceedings of ION GPS/GNSS 2003, Portland, OR,

[4] GI-Eye Precision Georegistration System,
  http://www.navsys.com/Products/gi_eye.htm.

[5] Analog Devices Accelerometers,
  http://www.analog.com/UploadedFiles/Data_Sheets/573918736AD
  XL350_250_0.pdf.

[6] Analog Devices Gyroscopes,
  http://www.analog.com/Analog_Root/sitePage/mainSectionHome/
  0,2130,level=4%255D%252521DF%3D%252526Language%3D
  3DEnglish%25251level=1%25250level=2%25250level=12%25253
  D310%2526level=13%25250level=2%25252D1.00.html.

[7] HG1700 Specification,
  http://content.honeywell.com/des/assets/datasheets/ds7
  hg1700_imu.pdf.

[8] Crista IMU Specification,


[10] A. Brown and D. Sullivan,
    Precision Kinematic Alignment Using a Low-Cost GPS/INS System,
    Proceedings of ION GPS 2002, Portland, OR, September 2002,

    Inertial Navigation Electro-Optical Aiding During GPS Dropouts,
    Proceedings of the Joint Navigation Conference 2002.,
    Orlando, FL, May 2002,

[12] S. Pender, D. Boid, D. Sullivan and A. Brown,
    Video Updates During GPS Dropouts Using Navigation and
    ElectroOptic Sensor Integration Technology,
    Proceedings of the 58th Annual ION Meeting,
    Albuquerque, NM, June 2002,

[13] A. Brown and P. Sack,
    Navigation Using LINK-16 GPS/INS Integration,
    Proceedings of ION GPS/GNSS 2003,
    Portland, OR, September 2003,

[14] F. Carpenter,
    PC/104 Test-Bed for Software GPS Receiver (SCR) and Software
    Defined Radio (SDR) Applications,
    MPRG's Wireless Communications Symposium,
    Virginia Tech., June 2004,
IMA Aircraft Improvements

Chris Wilkinson
University of Maryland

ABSTRACT

Integrated Modular Avionics (IMA) is being suggested as the means by which new capabilities can be deployed on aircraft at an affordable cost. RTCA SC-200 is presently considering the guidance document for IMA. All of the functionality that IMA offers can be achieved through a conventional federated architecture; however, the cost, size, and weight penalties of the federated solution make it economically infeasible. IMA is seen as the way forward. It is assuming greater importance as the aircraft industry transitions to Commercial-Off-The-Shelf (COTS) technology with its attendant obsolescence and reliability concerns. IMA may be one of the most cost-effective ways by which rapid obsolescence can be managed. Ironically, this move to COTS is also the greatest threat to IMA systems.

IMA achieves reductions in size, cost, and weight by providing a set of flexible hardware and software resources that can be statically or dynamically mapped to a set of required avionics functional capabilities. This introduces a number of new complexities such as mixed criticalities and reconfiguration. We do not address these issues herein. Rather we discuss the mechanisms by which electronics degrades and how a classical safety assessment of a reconfigurable IMA system can be nullified by this degradation.

We argue that, with the advent of COTS, it is no longer justifiable to consider that electronics has an effectively constant failure rate. Physical considerations suggest that electronics failure occurs when environmental and operating stress causes the accumulation of damage to the underlying structures to exceed the threshold strength of the constituent materials and interfaces. Finally, we suggest how finite-life electronics effects may be mitigated.

Table 1. Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC</td>
<td>Central Maintenance Computer</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial-off-the-Shelf</td>
</tr>
<tr>
<td>FMECA</td>
<td>Failure mode effects and criticality analysis</td>
</tr>
<tr>
<td>HM</td>
<td>Health monitor</td>
</tr>
<tr>
<td>IMA</td>
<td>Integrated Modular Avionics</td>
</tr>
<tr>
<td>LRM</td>
<td>Line Replaceable Module</td>
</tr>
<tr>
<td>LRU</td>
<td>Line Replaceable Unit</td>
</tr>
<tr>
<td>MMEL</td>
<td>Master minimum equipment list</td>
</tr>
<tr>
<td>PHM</td>
<td>Prognostics and health management</td>
</tr>
</tbody>
</table>

RELIABILITY

LRM reliability is most usefully considered as a competing risk model, since LRM's are most likely to be individually non-redundant. The effects of redundancy can then be considered in terms of the basic LRM at a higher level. In this model, the LRM fails at the first failure of the competing mechanisms, i.e., a series model.

Electronic equipment failure rate is typically illustrated by the well-known bathtub curve, Figure 1. Initial shakeout reliability is characterized by a falling hazard (failure) rate followed by a roughly constant hazard rate, and, lastly, a rising curve as wear-out failures begin to occur. The data used to plot this curve is usually of a rather gross kind due to the great difficulty of obtaining detailed fault information from the field and maintenance shops. The data often does not distinguish between the large varieties of failure mechanisms (competing risks) that cause the reported failures. When this is taken into account, the relatively flat portion of the curve is seen to be a
consequence of accumulating (summing in the competing risk model) a large number of non-constant hazard rate curves.

The right hand rising portion has usually been discounted in the past as being far beyond the expected service life of the equipment. With the increasing use of COTS, this assumption may no longer be correct [13].

There is evidence that leading edge semiconductors are being designed for a limited life commensurate with the end application [4]. In practice, this means computers, telecommunications, and consumer electronics. These all have product lives that are less than that typical for avionics. It is now, therefore, necessary to consider the implications of this end-of-life phenomenon.

SYSTEM SAFETY ASSESSMENT

A safety assessment (a certification requirement, e.g., [5]) is carried out by a top-level hazard analysis and by considering all possible failure modes effects and consequence (P-FMECA). The probability/hour of a functional failure event is required to meet the applicable regulations for the assigned system criticality level. It rarely occurs that a single channel system can meet the highest levels of safety assurance, typically a probability of function loss of $10^{-7}$/flight-hour, required for a critical function. Redundancy, voting, and reconfiguration (in various forms) are the most commonly applied techniques [6] to increase functional reliability to the required level where the separate channels are insufficiently reliable alone. Typical practice is to assume a constant failure rate, compute channel reliability by handbook methods and combine channels with classic reliability theory. The handbook methods have fallen into disrepute in recent years but continue to be used [7].

This simple, voted, k-out-of-n redundancy calculation is somewhat illusory, as it does not consider the damage accumulation effects that occur in both the active and standby channels. Reliability is strongly dependant on the operating environment, which is constantly changing. The standard analysis does not consider this variation or the occasional excursions to the extreme. Were these effects considered, it might be justifiable to reduce the level of redundancy (and, thus, size, weight, and power) and still meet the safety requirement.

It must also be said that system safety is not only a function of the reliability of its components. Many other system-level factors such as EMC, architecture, dissimilarity, segregation, and human factors play an important part. Nevertheless, reliability is central to the assessment.

DEFERRED MAINTENANCE

In IMA, one of the major design goals is to provide a set of multi-purpose and flexible hardware resources not dedicated to a particular function (Figure 2). This permits functions to be reconfigured among the available hardware resources in order to absorb faults to some degree. In time, the faults will accumulate to such a degree that there is no reconfiguration possible such that the dispatchability requirements can be met. An unscheduled maintenance action must then be carried out to repair the failures and restore air-worthiness.

Faults and non-critical failures need not be repaired until the aircraft returns to a central maintenance base, possibly
completing a number of revenue flights or missions in-between; then faults and failures are repaired. A deferred maintenance capability thus reduces the need for widely distributed support facilities and spares provisioning. Redundancy and reconfiguration is thus used to achieve both system safety and deferred maintenance.

**DISPATCHABILITY**

Aircraft dispatchability is currently determined by the present state of the various aircraft systems, the planned routing, and the ameliorative actions permitted to the flight crew. The present state is the combination of resources that are faulted or functional, either by their in-built health monitors (HM) or by some external means such as ground-crew testing or pilot “squawks.” Failures result in certain functions or operations being unavailable or curtailed but may not incur loss of dispatch depending on their criticality level and the planned routing.

In civil operations, the common mechanism for determining dispatchability is the MMEL required for every commercial aircraft model. The MMEL provides the logic necessary to determine dispatchability under all possible combinations of function loss and the planned routing.

The general-purpose nature of IMA resources permits many different configurations to provide the desired functionality. Since IMA is characterized by shared resources, these may degrade (e.g., partial memory loss, reduced processing speed, and out-of-specification power) rather than fail totally. This can lead to resource starvation and random function loss depending on the order in which functions grab the available resources. Thus, dispatchability is a more complex thing to determine in IMA compared to a conventional federated architecture.

In establishing the dispatchability criteria to be incorporated in an MMEL, it is necessary to consider that additional failures may occur during or after take-off. There is no forecast available when such an event may occur. Indeed, it is a consequence of the industry-practice constant failure rate assumption (also called the “good-as-new” or “memoryless” assumption that has been the mainstay of all reliability and safety calculations for many years), that a fault is equally likely to occur at any time (including time zero), since the hazard rate is assumed constant. A fault time forecast (with an agreed confidence level) permits the dispatch criteria to be relaxed if the forecast is commensurate with the available redundancy and flight duration (including possible diversions).

**REMAINING LIFE**

The go/no-go measure of system health determined by typical health monitoring (HM) functions is rather simplistic. In reality:

- Electronics has a finite life,
- Remaining life decreases with time,
- Remaining life vs. time is a complex function of environmental history, design tolerances, and material properties.

Assuming a constant failure rate (good-as-new) for electronics is not correct, since electronic structures such as electronic component packages, solder joints, PCB vias barrels, wires and connectors accumulate damage at a rate dependent on the experienced environment. It follows that electronics is not “memoryless” as commonly supposed. Good approximation models are available for the time taken for these to fail.

To decide whether this is of practical interest, we must consider what remaining life we should expect from the various modules, components, and structures that comprise an IMA system. Reference [8] shows that the lifetime is well within the typical operating life of an aircraft.

Uncertainties are inherent in any remaining life estimation. These arise from the sensor measurements, the models used to translate these measurements to local failure sites, the failure models themselves, the variability of material properties, and the necessary assumption of stationarity of the sensor measurement statistics. Consequently, remaining life must be described as a probability distribution with associated confidence interval whose limits are dependent on the confidence level the user desires to have in the prediction. The greater the confidence level demanded – the wider must be the confidence interval.

Avionics systems are generally designed to be repaired because of their cost and complexity. Repair (meaning replacement of something) can occur at many levels, e.g., component, circuit card, LRM, or possibly even LRU level. Repairing an item restores its functionality but does not restore its life status to “good-as-new” since the other components and structures remaining are untouched. Consequently, as time progresses, the life remaining in a functional item, is a function of its environmental history and its repair history. Therefore, to compute a remaining life of an LRM requires knowledge of this history at the lowest level of repair. It is a complex logistics problem to maintain this data at the point of use. This complexity drives the economics and may dictate the lowest level of repair that should be included in any logistics plan.

The life function has been studied by many workers resulting in a variety of failure models (see Table 2) being developed. Since design tolerance and material properties are not known exactly, they can only be described by probability distributions whose parameters are determinable from a wide range of experimental sources. Environment can be measured by monitors placed around the airframe but even so, the measured environment values are not those that are experienced by the inner workings of the electronics and a translation is required, adding to the uncertainty.

The remaining life of electronics is therefore a probabilistic measure that must have a range of uncertainty but that
Table 2. Examples of Life Models

<table>
<thead>
<tr>
<th>Failure Mechanism</th>
<th>Failure Sites</th>
<th>Relevant Stresses</th>
<th>Sample Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Die attach, Wire bond/TAB, Solder leads</td>
<td>Cydic</td>
<td>Nonlinear Power</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Bond Pads, Traces, Vias/PTHs Interfaces</td>
<td>Deformations</td>
<td>Law (Coffin-Manson)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta T, \Delta H, \Delta V$</td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td>Metallizations</td>
<td>$M, \Delta V, T,$</td>
<td>Eyring (Howard)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chemical</td>
<td></td>
</tr>
<tr>
<td>Electromigration</td>
<td>Metallizations</td>
<td>$T, J$</td>
<td>Eyring (Black)</td>
</tr>
<tr>
<td>Conductive Filament</td>
<td>Between Metallizations</td>
<td>$M, \Delta V$</td>
<td>Power Law (Rudra)</td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress-Driven</td>
<td>Metal Traces</td>
<td>$\sigma, T$</td>
<td>Eyring (Okabayashi)</td>
</tr>
<tr>
<td>Diffusion Voiding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time-Dependent</td>
<td>Dielectric Layers</td>
<td>$V, T$</td>
<td>Arrhenius (Fowler-Nordheim)</td>
</tr>
<tr>
<td>Dielectric Breakdown</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\Delta T$ Temperature Range  
$T$ Temperature  
$\Delta H$ Humidity Range  
$\Delta V$ Voltage Range

$V$ Voltage  
$M$ Moisture  
$J$ Current Density  
$\sigma$ Stress

Uncertainty can be quantified. A fundamental result is that the user must understand that the more confidence they wish to achieve, the wider must be the resulting interval. As the interval widens, the equipment is replaced earlier and so there is increased waste of remaining useful life.

Whether this wasted useful life has an overall negative impact on the fleet life cycle cost is an economic question whose answer depends strongly on the cost structure of the support organization.

PROGNOSTICS

Reconfiguration following a fault will restore the lost capability only provided we assume that the reconfiguration has swapped in a module that has enough remaining life to survive the rest of the flight or there are further modules available that can step in as necessary and that this sequence together has enough remaining life. Since the “good-as-new” assumption is not correct (they consume life simply by being
there), this will not be the case. Therefore, as part of the pre-flight checks and reconfiguration process prior to take-off, account should be taken of the remaining life of those modules that might be called upon in the event of further faults occurring by incorporating a remaining life estimate into the IMA.

There are two options to consider when mechanizing the estimation of remaining life. The calculation can be carried out by an on-board function (CMC, for example) or environmental history can be downloaded to a ground-based maintenance facility for off-line computation of remaining life. In either case, remaining life is computed from stored (relatively constant) data on the IMA configuration and design definition. In order to keep this data up-to-date as the design evolves, some automated update would be desirable.

It will always be technically out of reach to predict all future times of failure. A certain proportion must be classified as “random” simply because they result from unexpected causes and thus we have no models to predict them. They could be considered to have a constant, hopefully negligible, rate of occurrence. Our aim is a process that combines estimates of time to failure of the dominant (and known) mechanisms with a residual low constant failure rate to estimate the fitness of an IMA module.

---

Fig. 3. Remaining Life Prediction

Fig. 4. LCM Test Board Mounted on Car Chassis

Fig. 5. Remaining Life Assessment

A process for PHM is shown in Figure 3. Sensor data provided by a variety of on-aircraft sensors is first compressed and reduced. This process greatly reduces an otherwise unmanageable quantity of data, without sacrificing a significant amount of information. A life consumption algorithm, utilizing a variety of life models, knowledge of the design, and the constituent material properties, then computes the amount of life used with an associated confidence interval for each of the possible failures sites. Since there are sources of uncertainty, such as material properties and the physical
dimensions of the various structures making up the electronics assembly, there is corresponding uncertainty associated with the life consumption computation. The reasoning process combines these uncertainties using a decision support system to give a remaining life prediction for the complete system, again with an associated confidence interval.

CASE STUDY

As a simplified example of the application of life consumption monitoring to an on-vehicle electronics item, CALCE has estimated the life remaining in a test electronics module mounted under the hood of a car [9]. Two experiments were conducted, one with the module located on the exhaust manifold and the second with the module mounted cantilever fashion (Figure 4) on the chassis inside the engine compartment.

A commercial sensor data recorder was used to monitor the environment. The data analysis steps and the remaining life assessment process steps are shown in Figure 5.

These experiments sought to demonstrate that under combined environment conditions (i.e., simultaneous temperature cycling and vibration), separate computations of damage accumulation could be additively combined to produce an overall damage accumulation. This is illustrated in Figure 6 where the individual and combined accumulated damage is plotted as a function of elapsed time (this particular car suffered an accident after 22 days resulting in an additional shock component being added). This study did not include estimation of the confidence interval that should be attached to the remaining life prediction.

The experimental results are shown in Table 3.

MITIGATION

The effects of degradation can be mitigated by ensuring that the IMA is able to report remaining LRM lives to the HM sub-system and that MMEL dispatch criteria take account of this in assessing what reconfiguration (if any) can assure safe flight and landing. This may mean that maintenance actions will need to be performed on items that are currently functioning correctly, but cannot be confidently relied upon to complete the next leg.

CONCLUSION

The constant failure rate assumption that is inherent to most certification regulations and the industry practices that flow from that is not soundly based. The health of a system is not measured simply by its functional status at a point in time but is a function of the remaining life in each of its component parts, including the redundant backups.

The confidence attached to system safety by the provision of multi-level redundancy is misplaced as these backups have also consumed part of their inherent life simply by being flown around, whether or not they are involved in any active flight control.

<table>
<thead>
<tr>
<th>Table 3. Remaining Life Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial VQ prediction based on SAE environmental handbook data</td>
</tr>
<tr>
<td>Life Consumption Forecast</td>
</tr>
<tr>
<td>Actual Life (to 15 readings &gt; 300ohms)</td>
</tr>
</tbody>
</table>

Fig. 6. Damage Accumulation

We suggest that system safety assessment and logistics planning be based upon a remaining life calculation using a representative environmental profile and that dispatchability status be continually updated by the same means using the experienced environmental history.

REFERENCES


[3] Shawlee, W., How Parts and Systems Age,

This forecast was reduced to 40 days when the additional damage arising from the accident was factored in.
[4] Huber, S.,
Segmentation and Reliability,
DMSMS Conference,

[5] Society of Automotive Engineers,
Guidelines and Methods for Conducting the Safety Assessment
Process on Civil Airborne Systems and Equipment,
ARP 4761, November 1996.

[6] Spitzer, C.R.,
The Avionics Handbook, ed. R.C. Dorf,
2001. The Electrical Engineering Handbook Series,

[7] Pecht, M., Boullie, J., Hakim, E., Jain, A.K., Jackson, M., Knowles, I.,
Schröder, R., Strange, A. and Wyler, J.,
The Realism of FAA Reliability-Safety Requirements
and Alternatives.

[8] Valentin, R., Cunningham, J., Ostermaa, M., Dasgupta, A.,
Pecht, M.G. and Tsagos, D.,
Virtual life assessment of electronic hardware used in the
Advanced Amphibious Assault Vehicle (AAAV),
Proceedings of the Winter Simulation Conference,

[9] Mishra, S., Pecht, M., Smith, T., McNeel, I. and Harris, R.,
Remaining Life Prediction of Electronic Products Using
Life Consumption Monitoring Approach,
European Microelectronics Packaging and
Interconnection Symposium, Cracow, Poland, June 2002.

[10] Ramakrishnan, A. and Pecht, M.G.,
A life consumption monitoring methodology for electronic systems,
Components and Packaging Technologies,
IEEE Transactions on [see also Components, Packaging
and Manufacturing Technology,
Part A: Packaging Technologies, IEEE Transactions on],
The Rolling Radar

Byron W. Tietjen
Lockheed Martin Co.

ABSTRACT

In the search for a better rotating radar, a self-supporting array that rolls like a wheel can improve mechanical reliability and return higher-definition target resolution [1].

The Rolling Radar concept evolved from the need to design and build a large rotating 3D radar as an alternative to multifaceted fixed radar installations, or large, expensive rotating radar systems. However, the physical act of rotating massive structures weighing many tons introduces a host of load bearing and other mechanical reliability problems. An alternative design needed to be conceptualized.

The new concept places the radar array inside a large wheel attached to an axle. A smaller wheel affixed to the axle’s other end provides support when both wheels simultaneously roll along electrified concentric rails in order to scan 360 degrees.

The array wheel propels itself via a simple gravity drive consisting of a magnetic carriage that rides an electromagnetic rail around the inside circumference of the large array wheel. Displacement of its own weight causes the wheel (and the entire axle) to roll around the railed track with no visible external means of motion.

The Rolling Radar achieves its initial objective – to improve mechanical reliability – because the array wheel is self-supporting, which eliminates the need for a large support structure and bearing. There is also no need for traditional electrical slip rings, rotating fluid couplers, motors or gearboxes. With fewer moving parts (compared with conventional rotating radars), reliability is increased and life cycle costs are reduced.

Another important benefit is the Rolling Radar’s electronic look back capability, and the ability to achieve higher spatial resolution than standard 3D radar. This occurs because the act of rolling about its axis and simultaneously rotating about a circumference sweeps a larger area than the array’s physical aperture. The effect is similar to spotlight-mode synthetic aperture radar (SAR), a technique commonly used to produce high-resolution radar maps.

The Rolling Radar concept was initially developed to address reliability, life cycle cost, and weight. Although still in the concept development phase, the Rolling Radar shows great promise of increasing functionality while improving resolution and reliability, and in its simplicity of design. Both the reliability and performance gains are in the process of being evaluated.

INTRODUCTION

The Rolling Radar concept was born of the need to develop a large, high power rotating radar free of the problems normally associated with systems weighing more than several tons. Conventional designs are prone to high failure rates of their moving and load bearing components, which reduce reliability and availability while increasing operating costs. Particularly vulnerable are:

- **Load-Supporting Bearings** – The combined weight of a large rotating platform and support structure (on the order of 10-40 tons or more) places tremendous high wear rates on the large bearings that enable the antenna to rotate. Worn bearings add to system failure, and are costly to replace. For example, the FPS-24 antenna was a large, heavy weight radar for which bearing related problems often occurred [2].

- **Motors and Gearboxes** – Motors and gearboxes are normally used to rotate radar arrays. As moving and torque-transferring components, these are subject to relatively high wear and failure rates. High failure rates tend to prolong repair time, decrease operational availability, and increase spares costs.

- **Power Slip Rings** – Normally, slip rings are used to transfer power to the array as it rotates. As a
Fig. 1. Rolling Array Wheel and Axle

Fig. 2. Rolling Radar Concept

moving part, the slip ring is subject to relatively high failure rates. In addition, slip rings large enough to handle the high current loads of large radar systems can be difficult to find.

- **Fluid Couplers** – If fluid cooling is required, mechanical fluid couplers ensure delivery of a continuous flow of coolant to the rotating energy-emitting array. Couplers tend to leak fluid, especially when they become worn.

While fixed radar installations require no slip rings, fluid couplers or load supporting bearings, they do require more than one array to cover 240 or a full 360 degrees. Assuming the mechanical portion of a rotating system to be less costly than additional arrays and their associated electronics (the most expensive portion of today’s radars), the cost of equipping a multi-array system must be weighed against the benefits of a reliable single array that rotates.

Fig. 3. Platform / Array Diameter

But a large rotating radar can only produce long-term cost and operational benefits if designers can address the issues of mechanical reliability and related maintenance.

To produce a cost-effective large rotating radar, a high degree of reliability must be introduced into the design – not an insignificant challenge.

**ROLLING RADAR BASIC DESIGN**

The Rolling Radar design places the antenna array inside a large diameter wheel attached to an axle (Figure 1). A smaller diameter wheel at the axle’s other end supports the array wheel as the combination rolls around a concentric set of electrified rails as shown in Figure 2. The following attributes of this basic configuration directly address the issues of mechanical reliability:

- **Self-Supporting Array**

  The array wheel bears the weight of the array electronics, eliminating the need for a large support structure and bearing. A flange keeps the wheel on the rail as it rotates. The support wheel balances the array wheel, and provides adjustable vertical field of view (FOV) tilt to the array wheel.

- **Powered Rails**

  Electrified rails not only support the array wheels, they also bring transmission power up to the electronics inside the array wheel. Electric power is transferred to the array as a rolling surface contact similar to an electric railroad or subway car (Figure 2), obviating the need of a slip ring for power.

- **Platform**

  The electrified rails sit on a support platform of sufficient strength to handle the weight of the array-axle assembly. Platform size is a function of the array size and the tilt angle of the support wheel. Figure 3 shows the ratio of platform diameter to array diameter as a function of array tilt angle.
Gravitational Drive

Large motors and gears that rotate the array in conventional rotating radars are replaced in the Rolling Radar design by a gravity drive system that induces enough gravitational energy to set the array wheel in motion. The drive consists of a weighted magnetic carriage assembly that rides a segmented electromagnetic track around the wheel’s inside circumference.

Similar to a linear induction motor, the electromagnetic segments pull and push the carriage around the track circumference. As the carriage rotates, it displaces the array wheel's balance (see Figure 4), causing the wheel to roll.

To ensure the wheel rotates at a constant velocity, a servo system energizes the appropriate segments of the EM track in order to maintain a constant moment. The servo can also move the array to a predetermined azimuth by bringing the moment to zero in a controlled fashion as the array approaches the desired position. This will provide the ability to stop and stare at a target of interest for increased accuracy and burn-through.

Fluid Cooling System

If fluid cooling is required, as may be the case for a multi-megawatt system, the rolling radar design draws fluid coolant from a reservoir located in the center of the platform behind the support wheel. The coolant is pumped from the reservoir to the array electronics via tubes that run through the axle. This coolant tube is always immersed in the fluid reservoir, and simply moves through the fluid as the array rolls around the railed track. This removes the need for traditional fluid coolers. After cooling the electronics, the heated fluid simply runs back down the axle into the fluid reservoir (see Figure 5). The fluid in the reservoir is cooled by one or more stationary off-platform heat exchangers.

Maintenance

The array wheel’s ability to roll can facilitate easy array maintenance. For example, a partial roll of the wheel will
position a bad component into a lower position for easier access and replacement. A maintenance platform – permanently affixed to the gravity drive carriage – requires a height only half the array diameter to provide access to any failed component (see Figure 6).

Access to this area would be straightforward via access doors on the back of the array, as the carriage assembly will always be at ground level and vertical when the array is at rest (see Figure 7).

**DESIGN CONSIDERATIONS**

If operators are to take advantage of the Rolling Radar’s increased mechanical reliability, engineers must consider the following design aspects:

**Determining Azimuth**

To accurately localize a target, the Rolling Radar must know at all times the azimuth position and orientation of the array (in relation to the axle). But to maintain high reliability, mechanical links such as traditional servos were rejected.
One solution lies with an optical sensor located near the base of the axle. Consisting of a ring of laser diodes or video equipment (Figure 8), the sensor reads an optical bar code on the fluid reservoir in the center portion of the array platform. For more accuracy, there is the option of placing the optical code on or near the tracks, with the active optical sensor ring located near the wheel perimeter. The optical data is processed to precisely determine array position and orientation for beamsteering, target position determination, and servo control.

This or a similar optical link may also be used as a data link between the array and off-board command, control and display processing.

**Beam Steering**

The Rolling Radar must be able to point a radar beam in any direction within the array field of view (FOV) to enable the array to scan an arbitrary angle. This capability requires compensation for the array's dual axis motion, and an element or small sub-array based array processor that can maintain the appropriate phase and time delay control for beam forming. Assuming this is to be done digitally, Figure 9 provides an estimate of expected computational rates per array element as a function of sampling rate (Fs) for various operational bandwidths.

The ability to form a beam that can point in any direction relative to the array is mandatory by virtue of the array's rotation about its axis. This capability also enables the rolling radar to have an electronic look back feature which will allow it to stare at targets of interest while the array is rotating. Other capabilities associated with element based processing will also be provided, such as adaptive beamforming, sidelobe canceling, etc. A generic processing block diagram is given in Figure 10.

**ADDITIONAL BENEFITS**

Having addressed the issues of mechanical reliability, previously undiscovered benefits of the Rolling Radar design were quickly realized: higher resolution target imagery, multiple frequency capability, and ease of deployment for smaller, mobile applications.

**Higher Resolution Target Imagery**

An extraordinary benefit of the Rolling Radar array is that it can return a higher resolution image of the target than an array of identical size on a conventional rotating radar. The phenomenon occurs because the Rolling Radar subtends, or spans, as it travels, an aperture which is larger than the array's physical size (see Figure 11).

Specifically, the Rolling Radar can provide a few dB of performance improvement in azimuth angular resolution – itself a key parameter in target characterization.

The effect is akin to that achieved by spotlight mode Synthetic Aperture Radar (SAR) systems flown aboard aircraft to provide high-resolution reconnaissance and targeting information [3]. SAR systems obtain fine azimuth resolution by collecting data as the antenna travels across distances of several hundred meters, and then processing the data as it came from an antenna of the same physical length. The distance the aircraft flies in synthesizing the antenna data is known as the synthetic aperture.

In the case of the Rolling Radar, the gain in virtual array size over the size of the physical aperture results from the array size and tilt angle, and the azimuth FOV. Figure 12 plots the ratio of virtual aperture size to array physical size, as a function of array tilt angle for various azimuth scan angles or FOV. This may allow a lower frequency to be used to achieve a specified resolution. Lower frequencies can bring a host of additional benefits such as more efficient RF amplifiers, lower cost array by virtue of needing fewer elements, lower power required for given range performance, and higher dynamic range analog to digital converters.

**Deployment**

While large radars are difficult and expensive to deploy because of the physical size of the support platform, the Rolling Radar requires only a platform sized to the set of concentric tracks that support the array and axle wheels. This would lend itself to field deployment as shown in Figure 13. This is shown complete with a centrally located Identification Friend or Foe (IFF) antenna, which can rotate independently of, or in synchronization with, the Rolling Radar array (shown is an air-cooled version).

This configuration, coupled with the ability of the Rolling Radar to process virtual aperture data and propel itself around the tracks, suggests that an arbitrarily large virtual aperture can be fabricated by simply increasing the track diameter, and adjusting the tilt angle of the array via selecting the appropriate diameter for the rear wheel. For small radar applications, the rolling design can be sized for transportation and mobile deployment.

**Dual Frequency Capability**

The Rolling Radar concept can scan dual frequencies by placing multiple rolling axle arrays on a single set of tracks.
For example, a dual frequency configuration could simultaneously scan with a UHF-band search radar and an X-band radar for high definition processing from the same platform. There is also additional room beneath each rolling array for peripheral equipment, such as anti-missile missiles, shelters, cooling units, etc. This configuration can avoid the added costs of multiple platforms (Figure 14).

**FUTURE EFFORT**

Future effort to prove the Rolling Radar concept will involve several tasks:

1. **Reliability and Life Cycle Costs:** Preliminary analysis indicates that the reliability of Rolling Radar will be considerably better than traditional rotating radar designs, and can even approach that of multi-faceted, fixed array systems. Further analysis of the Rolling Radar concept is required to better quantify the design's high reliability versus traditionally designed rotating radars, and the design's cost-effectiveness compared to large, fixed multi-faceted arrays. Specifically, the tribological aspects of the wheel/axle assembly and their rolling surface contact will need to be evaluated in terms of wear and expected life [4].

2. **Optimum Frequency Selection:** With the added features of the Rolling Radar over traditional designs such as synthetic aperture capability, an evaluation of the optimum frequency band to use may result in a less expensive system when compared to traditional designs.

3. **Signal/Signal Processing:** Further analysis and modeling of the beam forming and signal processing functionality of the Rolling Radar is necessary to determine processing capabilities and limitations. For example, the ability of the system to beamform while rotating will depend upon the ability to accurately know the array position, size of the array, frequency, rotation rate, etc. This effort would quantify system performance and identify realistic constraints and limitations, and the impact of errors.

4. **Direct RF Conversion:** The Rolling Radar will require element (or small sub-array) based processing which, to date, has been an expensive undertaking. A cost-effective approach is needed. The evaluation of a novel design of a direct RF converter for this purpose is currently underway.

5. **Synthetic Aperture:** A synthetic aperture has the potential to increase the azimuth angular accuracy measurements beyond what achievable by

---

**Fig. 14. Single Platform, Dual Radar Configuration**

the physical array itself. Analysis would determine capabilities and limitations of the system in this regard, and quantify expected gains.

6. **Electrical/Mechanical Design:** As with any new concept, the Rolling Radar concept answers some questions, and raises others. Since this design has not been attempted before, careful evaluation of the design is required, especially of the following:

- Internal Gravity Drive and Servo Mechanism
- Rail Power Transfer System
- Array Structure
- Array Electronics Architecture
- Fluid Cooling System
- Array Position Indicator
- Tribology of Wheel/ Axle/ Rail Assembly
- Processing Architecture

7. **Safety:** The safety aspects of electrified rails and a large rolling wheel assembly will also need evaluation.

8. **Prototyping:** Once the above analyses and design evaluations are complete, the next step would be to build a small but fully functional prototype Rolling Radar. A radar prototype built to test a sample set of performance specifications could demonstrate the design's attributes, capabilities, and limitations.

**SUMMARY**

This paper presents the Rolling Radar concept as an alternative design for traditional rotating radar systems. The
intent is to develop a design as free of moving parts as possible in order to increase reliability, and also to provide a cost-effective alternative to large rotating arrays, and large, fixed, multi-faceted systems.

In this regard, the Rolling Radar design:

- Eliminates slip rings, large load supporting bearings and array support structures, motors, gearboxes, and rotary fluid couplers
- Propels itself using gravity in a self-contained azimuth drive
- Increases azimuth resolution via a virtual aperture and synthetic aperture processing
- Can employ multiple frequency radars on a single platform
- Is self-supporting (within a wheel) mounted on a set of tracks
- Provides all the features of an element based array such as electronic look back capability for target burn-through.

The design can be applied where operators require long range, 3D, full azimuth coverage for applications at home and abroad. The design is mechanically simple, reliable and cost-effective, and may even compare favorably to multi-faceted, fixed array systems. The design can also be scaled down for mobile applications. Analysis and prototyping of a fully functional Rolling Radar are the next steps to be taken.

REFERENCES

[1] Lockheed Martin has filed for and received patent protection on the innovative aspects of this recently developed technology (US Patent Nos. 6,512,904; 6,646,616; 6,753,822).


Satellite Data Collection & Forwarding Systems

Mirko Antonini, Aldo De Luise, Marina Ruggieri & Daniele Teotino
University of Rome "Tor Vergata"

ABSTRACT

A possible classification of satellites can be related to their capability to provide or not provide real-time services. Non-real-time systems store the information, and forward it to destination later, usually by means of Low Earth Orbit (LEO) satellites. Nowadays the main application of these systems is small data exchange to/from remote sites where no other communication infrastructure is available, hence, covering a niche market. Low on-board memory storage capability and, moreover, low bit rate due to little bandwidth allocated for these systems do not allow us to collect and forward a considerable volume of data in the short visibility window of the satellite passage. New applications and services can be conceived through the deployment of new systems able to overcome the above-described limitations, while existing applications can be provided more cost-effectively. These aspects are addressed together with an experimental interactive system which allows huge data collection in W-band and for forwarding to the Internet.

INTRODUCTION

The recent history of satellite systems has shown how the role of satellites and their potential capabilities are not fully clarified or exploited yet. The search for a killer application in the satellite field has not still an answer and the market failure of ambitious systems have cooled the enthusiasm of investors. The reasons of these failures are manifold, mainly due to optimistic market analysis (an example that has changed the business plan of many investors is the case of IRIUM systems [1]).

The development of beyond third-generation mobile networks foresees a seamless heterogeneous integration between terrestrial and space segments: to this respect, the role of the satellite as backbone, back-up, or integrated component of the terrestrial network has still to be fully defined [2]. Nonetheless, it is clear that satellite systems are very well-suited to support data applications and services: huge amount of data are easily transferred via satellite avoiding the congestion of terrestrial networks, for a fully global transmission.

Data can be stored on-board and forwarded in a subsequent period of time, with a delay acceptable in most applications. The class of store and forward satellites works on this principle. However, these satellites have been conceived to forward little data volumes. New applications and services could be conceived if a new class of satellites – able to collect and forward huge data volumes – could be deployed.

Such systems could be easily integrated with terrestrial networks, providing an added value to the overall system. In this frame, it is important to insight their potentialities and to identify key areas for improving their capabilities; this is the aim of the present paper.

The paper is organized as follows: after a brief overview about the features of data collection and forwarding through satellites and architectural design considerations in the following section, a list of possible services that can be offered by those systems is presented in the section entitled “Future Scenarios for DC&F Systems” and a real case analysis is carried on in the David Data Collection Experiment (DCE) section. Finally, conclusions and perspectives are drawn in the fifth section.

EVOLUTION OF STORE AND FORWARD SYSTEMS

A satellite system based on the paradigm of the digital Store and Forward (S&F) allows non-real-time communication [3, 4]. The best orbit-type for a S&F satellite is a LEO, thanks to many “orbital slots” available (with different altitude of the satellite and inclination of the orbital plane), low launch cost and, moreover, coverage of wide areas even with a single satellite.

The basic S&F architecture includes an originating ground station which sends the data to a LEO satellite; the satellite regenerates the data and stores the information in an on-board memory; the destination ground station retrieves the data at the first useful passage of the satellite. The service provided is,
Table 1. Services Performance

<table>
<thead>
<tr>
<th>SERVICE</th>
<th>DELAY</th>
<th>COVERAGE</th>
<th>DATA RATE</th>
<th>MEMORY</th>
<th>BANDWIDTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telemedicine</td>
<td>0-24 hours</td>
<td>World</td>
<td>10 Mbps</td>
<td>10 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Biosensor data</td>
<td>0-24 hours</td>
<td>Urban</td>
<td>60 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Video surveillance</td>
<td>0-24 hours</td>
<td>Urban</td>
<td>80 Mbps</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Infrobility</td>
<td>Few hours</td>
<td>Country</td>
<td>100 Kbps</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Fleet Management</td>
<td>Few minutes</td>
<td>Continent</td>
<td>100 Gbps</td>
<td>1 Gbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Automatic marine sensors</td>
<td>12-48 hours</td>
<td>Country</td>
<td>100 Gbps</td>
<td>1 Gbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Software supply</td>
<td>0-24 hours</td>
<td>World</td>
<td>60 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Audio and voice transact</td>
<td>0-24 hours</td>
<td>World</td>
<td>10 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Multimedia kiosk</td>
<td>1 week</td>
<td>Continent</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>D-Cinema</td>
<td>12-48 hours</td>
<td>World</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Remote ERP</td>
<td>Few hours</td>
<td>World</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Military applications</td>
<td>Few hours</td>
<td>Territory</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>File transfer on demand</td>
<td>0-24 hours</td>
<td>World</td>
<td>100 Mbps</td>
<td>1 Gbps</td>
<td>100 Mbps</td>
</tr>
</tbody>
</table>

therefore, basically a point-to-point one. The served area and the delay of transmission are only functions of the number of satellites deployed and the selected orbit.

Most of the systems developed since now (ORBCOMM, GONETS, LLMS-IRIS, E-Sat, LeqO, KITComm, etc.) have bandwidth allocation of few MHz, below 1 GHz [5]. Therefore the bit rate achievable is low, and the data volumes which can be transferred is limited, also due to the limited visibility offered by the satellite.

Innovative Data Collection and Forwarding systems (DC&F) could be conceived when large bandwidth will be available. Shifting from present Ku-Ka bands to Q, V, and W bands would allow us to achieve much wider bandwidth. Furthermore, smaller antennas could be conceived, yielding to terminals with reduced size and weight for ease of transportation.

Huge data volumes transfer could be reasonably performed not only on a point-to-point basis, and a suitable integration with terrestrial networks could be envisaged to empower the overall system performance.

FUTURE SCENARIO FOR DC&F SYSTEMS

A broad range of services can be conceived and provided by means of DC&F through satellites. Each service can be mainly characterized in terms of data volume or, equivalently, bit-rate. In fact, assuming (quasi) delay-insensitive applications, the system aims at collecting (and subsequently forwarding) as much data as possible during the satellite passage. This could be achieved relying on both on-board memory capacity and high bit-rate capability.

An example of some of the possible services that could effectively exploit DC&F features are shown in Table 1. For each application, user needs in terms of QoS are translated into minimum system requirements. Delay is defined as the time intercourse between data uploading from user or service provider and data downloading. Coverage field is a measure of the distance between users or between gateway and users. These parameters have a direct influence on LEO orbit constraints. Data rate and on-board memory capacity measure payload performance, then high frequency band requirement is marked if an application requires high data rate link or portable user terminals.

These services are described in the following, pointing out their main features.

Teledicine

Teledicine is the capacity to practice medicine, provide medical consultation, diagnoses and distance teaching through the use of telecommunications, telemetry, and teleoperators. In recent years the most important fields of applications for teledicine have been teledermatology, teleradiology, telepathology, and telecardiology. New high-technology medical centers are emerging, that allow the exchange of information and scientific data and, hence, makes it possible to have diagnoses from very specialized centers working thousands of kilometers far from the patient.

![Fig. 1. Teledicine Scenario](image)

The Teledicine service envisages the following phases:

- Data acquisition
- Data digitalization and storage
- Data sending
- Remote expert consultation (telediagnosis or second opinion)

Teledicine information could be converted in raw data, as shown in Figure 1. Network performance for teledicine could be measured in terms of Quality Of Service (QoS) for the final user. A preliminary analysis has shown that telepathology is the field of application that needs major requirements in terms of bandwidth [6].

The anatomic pathology is a branch of the medicine that allows diagnoses based on the study of images or video-clips.
showing parts of the body. Images are in digital format. In case of images obtained with a CCD (Charge Coupled Device) camera connected to a microscope, the dimension of a single image can reach 5000 x 5000 pixels and the colour resolution 24 bits; the need of possible image magnifications can lead the size of the compressed raw digital data to be exchanged to about 100 Mbytes. The final users for telemedicine are specialized medical staff: in their work they follow tens of patients and remote expert consultation could be considered an appointment with a new patient.

Expert response (telediagnosis) could be sent within the same network used for telemedicine. In this scenario real-time communications is not a necessity and some hours waiting between data storing and data forwarding seems acceptable. In countries that lack infrastructures (for example, not connected to Internet) or specialization in some medical fields, telemedicine is of paramount importance. The capability of future satellite architectures in handling large amounts of data can, hence, render them dramatically important in the development of telemedicine.

File Transfer On-Demand

It is quite easy to imagine a near-term scenario where data transfer could come into a new idea of e-commerce. Some unmaterial concepts, such as music, images, video, and readings are conceptualized in daily use objects such as Compact Disks (CDs), photos, Digital Versatile Disks (DVDs), and books. All these objects are closely related to traditional commerce, where factories produce the items and a delivery chain provides their distribution in all shops.

Satellites could help in overcoming this approach by delivering data rather than objects to a large public, hence skipping some steps of the delivery chain and with no need for good stocks, eventually dramatically lowering distribution costs.

Furthermore, thanks to the inherent broadcasting capability of the satellite, the number of potential final users is higher with respect to traditional distribution, and transmission cost, that is related only to the file size, can be reduced. Satellite data delivery can be extended to every type of file transfer on-demand. For instance, tele-learning could be an interesting application, that could involve a sheer number of potential customers, ranging from a wide variety worldwide corporations requiring personnel training, to public institutions, such as universities. On the business side, back-up and synchronization of database, as well as computer aided design file transfer and file sharing among co-workers are other examples.

Data Transfer To/From Remote Sites

Sensors sited on fixed monitoring points, with remote environment monitoring purposes, could transmit their data using satellite link. Furthermore, sensors sited on private houses could monitor, record, and transmit data for automatic meter reading – satellite can store data and transmit them to a gateway and control station for final storing and processing.

Internet Service Providers (ISPs) service could be offered also in remote areas where no Internet access points are present. The service of a Virtual ISP (VISPs) is a truly a "push" one: the contents are stored on various locations by means of a satellite, hence data are updated and new information is added every passage adaptively to user preference. Considering medium size 10-15 Mbyte web sites, about 70-100 could be entirely mirrored within a single passage by a system able to collect 1 Gbyte of data.

Furthermore, the request of a particular user can be met also by means of "one-shot" long file data transfer, exploiting the facilities offered by the VISP. This could be very important in creating or sustaining industrial centers in developing countries, where a company often cannot afford the costs related to data transfer service infrastructure, while it could reasonably rent a connection from a VISP.

Telecontrol envisages the transmission of a set of instructions to remote instrumentation: an example of this type of application will be shown in the next section, where a system able to provide remote monitoring and tele-control services to an Italian base at Baia Terra Nova (Antarctica) will be described. For such application QoS can be measured in terms of delay between two different telemetry and/or tele-command sessions, as well as in terms of size of data transmitted per satellite pass.

Video surveillance could be thought as part of the tele-control system, but it refers to high size data transmission and storage. Satellite could be used to transfer daily-recorded video to a central unit or a company that provides data handling and storage.

Reportages, documentary films, or newsreel are often transmitted from remote zones. These video data are mainly sent from reporters to video editing centers through INMARSAT mobile terminals. Video and audio (from a camera or Video Tape Recorder) is played into a video encoder which digitises and then compresses the information. The size of the data depends on the compression factor and clip duration. Audio and video transfer from remote sites is a typical application where real-time delivery is not critical. Nevertheless, cost and time required to transfer a great amount of video data could be a great limitation for reporter's needs. Broadband digital LEO satellites could provide a viable solution to transfer video data.

Infomobility

For a large number of applications a bi-directional satellite link is not a necessity. Information needs for vehicle users are often geo-referenced and data could be collected and transmitted without user interaction. For instance, the GALILEO system [7] will include a 1-way message delivering channel in its navigation signal, for narrow-band transport safety communications. In this way users can take advantage of broadband broadcasting via satellite, with low cost receivers and low cost network: in many cases broadcast transmission is very useful to simplify satellite system architecture and to decrease cost.
If a receive-only terminal is available at user premises, satellites could be used as data provider to dispersed users. Low-cost satellites could be used for a commercial application of infomobility services. Contents can be broadcast to receive-only vehicular terminal and content files will be encrypted and grouped by topics. Each topic could consist of a commercial service with a common interest for a large number of users (news, stock exchange, meteo, point of interest, events scheduling, etc.). Data transmission could be sorted on geo-referenced groups, and data decryption of a given topic will be available to authorized users only. Authorization could be exploited using user terminals with smartcard reader for billing purposes. Content delivery gateway stations, placed in suitable sites, could perform data refresh in advance to transmitting phase. Low-cost receiving-only navigation/infomobility terminal with few kbytes of mass memory can notify users on local/regional news and/or territorial information [7]. Furthermore, satellite link at medium data rate could be used.

**Military Applications**

Modern warfare could rely on position localization and territory maps collected by satellite with sub-meter precision, with data volume in the order of Gigabytes. Therefore, war zone communications are often not restricted only to voice and commands, but data, video, and image distribution could become the main military application. For these reasons modern military communications need portable terminals and high data rate links. War zone geostationary-based links requires large fixed antennas, often placed on vehicles. Broadcast transmission toward large war zones could be unsafe with respect to possible enemy interception. A LEO satellite equipped with high frequency and high directive steerable antennas can obtain a positive link budget to use portable terminals, with a footprint radius of few kilometers (as shown in an applicable example in the next section). This dramatically reduces interception risks, allowing us to achieve a protected point-to-point link as shown in Figure 4. Antennas alignment needs for LEO satellite ephemeris knowledge, that shall be a military secret. Strategic base station deployment will minimize transmission delays and vehicular ones could have the function of satellite access gateways. For these reasons DC&F satellites could be used for point-to-point military high safety communications.

Gigabytes size satellite mass memory could be used for high security database dumping, or as terrestrial network backup avoiding the protection problems related to wired networks safeguard.

**DAVID DATA COLLECTION EXPERIMENT (DCE)**

In the set of envisaged applications depicted in the previous section, the DAVID (DATa and Video Interactive Distribution) satellite scientific mission of the Italian Space Agency can be framed [8]. One of the scientific aims of the mission is to prove the feasibility of a data collection system of high data volumes in W-band and their transfer to the Internet. The system is capable of collecting at least 1 Gbyte of information data during the short visibility time of each passage and store it on-board (the on-board memory is in the order of 2.5 Gbytes). The collection channel bit rate (100 Mbps) is quite high, also accounting for the experimental nature of the system: this could be achieved thanks to the bandwidth availability in W-band, and would be greatly enhanced when a better knowledge of W-band propagation impairments and technological improvements in the W-band front-end performance will allow deployment of commercial satellite systems.

Most services presented in the previous section would take great advantage from a higher data rate volume transfer.

**Fig. 2. Video transfer performance according to coding**

![Fig. 2. Video transfer performance according to coding](image)

During the short visibility time of each passage and store it on-board (the on-board memory is in the order of 2.5 Gbytes). The collection channel bit rate (100 Mbps) is quite high, also accounting for the experimental nature of the system: this could be achieved thanks to the bandwidth availability in W-band, and would be greatly enhanced when a better knowledge of W-band propagation impairments and technological improvements in the W-band front-end performance will allow deployment of commercial satellite systems.

Most services presented in the previous section would take great advantage from a higher data rate volume transfer.

**Fig. 3. Military scenario**

![Fig. 3. Military scenario](image)

A DAVID-like architecture could provide the telecommunication infrastructure for such type of services at reasonable cost. An analysis has been carried out, considering a small constellation with four DAVID-like satellites. The orbits of satellites are near polar and are not optimized for a specific site. With regard to a mid-latitude earth station (in particular, the Spino d'Adda station near Milan in Northern Italy at about 45° latitude has been considered) and a minimum elevation angle of 30 degrees for communication, the delay between the eight useful passages are shown in Figure 5. The...
Fig. 4. Visibility analysis for a 4 satellites DAVID-like constellation. The delay refers to the two subsequent accesses indicated in abscissa.

delays are always lower than 3.5 hours and a minimum of 25 minutes data transmission per day are guaranteed. The whole system is therefore able to collect up to 150 Gbits from a single location and, hence, the data could be delivered worldwide with the use of a small and cost-effective satellite constellation.

CONCLUSION

The satellite market could show profitable if wise exploitation of the satellite features (global coverage, broadcasting capability, low-cost deployment, etc.) is performed.

Satellites are very prone for data transfer and data are generally insensitive to delay (in a measure depending on the application that requires them); satellite systems for data collection (eventually interactively) and non-real-time forwarding have, hence, a variety of applications and great potential for the future.

In the paper these possible applications have been analyzed. Most imply transfer of huge data volumes, therefore requiring high on-board memory capacity and high bit-rate transmission. The present Store and Forward satellite systems generally operate in the VHF band, and allow data rates of a few tens of kbits per second, due to the low bandwidth availability, and hence their target service is limited data exchange (e.g., e-mail).

In the above frame, an example of a new experimental system is also presented: it will operate in W-band, and could collect data up to 100 Mbps. The result of that experimentation could be of paramount importance for the deployment of future operational systems with advanced data transfer services.

REFERENCES


Fiber-Optic Radar Calibration

Mikko Puranen & Petri Karha
Helsinki University of Technology, Metrology Research Institute &
Pekka Eskelinen
Helsinki University of Technology, Applied Electronics Laboratory

ABSTRACT

A simple fiber-optic radar calibration target is described. Its operation is based on a wideband fiber, a laser transmitter that is directly modulated by the down-converted radar signal and an optical diode receiver recovering said signal. Further up-conversion having a common local oscillator with the first mixer ensures fidelity of the calibration return. Measured useful bandwidth exceeds 200 MHz and practically any radar RF frequency can be handled when suitable mixers are employed. Amplifiers can be added to the down-converted path as desired to compensate for the fiber loss. Modulation and LO sweep provide easy ways of introducing artificial fluctuations and Doppler frequencies. Particularly pulsed radars are readily tested with the proposed scheme as no restrictions are posed by the radar's TR-switch delays.

INTRODUCTION

During the past sixty years, engineers and scientists have been using more and less ingenious hardware and even some tricks in order to be able to test and evaluate pulsed radars in their laboratories [1]. Commercial dedicated devices have been available in the open market since the late 1950s or so [2] and normal measuring instruments such as signal generators, spectrum analyzers, and amplifiers have been arranged to perform the required task. One of the very fundamental issues in radar calibration and testing has been — and still is — the need for a precisely delayed but otherwise very high-fidelity copy of the transmitted pulse [3]. Of course, a delay is mandatory if we want to simulate the physical distance between the radar and its target in our laboratory environment. However, even if we did not want that feature, the radar's TR (Transmit/Receive) switch and its dead-time, unavoidably, call for some postponement of the reply. This basic part of radar construction is highlighted in Figure 1 [4]. Besides this, many radar designs employ some form of sensitivity control as a function of distance (or time) [3] and thus a reply coming at zero delay would be processed in a way not representing the radar's true characteristics.

One elementary solution is to use a microwave signal generator with its built-in pulse modulator and take from the radar under test a sample of its PRF logic pattern, put some delay to it, and feed this to the generator's modulation input. Also the carrier frequency is rather easily phase locked to the radar's master oscillator, because in the lab we can utilize short cables [5]. Unfortunately, this scheme illustrated in Figure 2 will become more tedious when our radar gets additional advanced features into its RF signature. If the real processing performance must be evaluated, we have to find other means of creating the desired replies. Optical fiber provides a promising possibility to overcome some of the limitations of previously used delay chains [6]. They are stable, have very wide bandwidths and, after the introduction of modern communication applications, the cost of hardware has substantially dropped [7].
CONSTRUCTION OF THE TEST SET-UP

Our experimental design is illustrated in Figure 3. Two RF mixers are connected to a ferrite circulator that provides the common port to be connected to the radar under test. An adjustable or controllable attenuator can be used between the two units as required or, as shown in the picture, we can have a short free space path and two horn antennas. This works well if we can satisfy the far field requirement in our lab at the radar’s carrier frequency. One mixer works as a down-converter and the other as an up-converter. The mixers have a common local oscillator; for example, a DRO or a VCO, which is needed to perform a frequency translation to the operating band of the processing part marked as P and connected between the IF ports of the mixers. The difference in signal levels between the two mixer RF ports is so large that there is no practical risk of unwanted rat race coupling.

The processing part is further illustrated in Figure 4 in more detail. An optical fiber of predefined length produces the desired delay in time and has a very wide bandwidth, in practice several gigahertz [8]. Two amplifiers are used, one at the input and another at the output. They provide a flexible way of amplitude adjustment and have response times short enough for echo shaping, too. A diode laser transmitter and a suitable detector form the converter pair between the IF and optical signals. Figure 5 is a simplified diagram of the optical receiver that operates on 9 V battery power for months, because its bias current is just some micro amps. Dedicated electronics is needed to maintain optimum operation of the laser, most notably for constant bias current, and operating temperature [9]. The lease unit has a built-in thermistor as a sensor and the heating/cooling function is provided by a peltier element.

The prototype versions of the fiber-optic interfaces are shown in Figure 6. Commercially available RF/IF building
blocks were used as amplifiers. The low signal levels call for good shielding, which is here taken care of by the die-cast aluminum housings, and supply line feed throughs. The two control electronics boards were assembled in normal 19-inch rack style. Figure 7 illustrates the constant current supply [10] for the laser diode and the laser transmitter itself, mounted on the same circuit board. Some adjustment is provided for the laser temperature with the multimeter potentiometer that is visible in Figure 8, which depicts the PID controller [11]. The entire assembled processing unit is shown in Figure 9. It has a monitoring display for the diode current and some LEDs to aid in a smooth start-up procedure.

**MEASUREMENT RESULTS**

Some preliminary tests have been carried out with the set-up but by using ordinary laboratory instruments instead of a real radar. Two parameters have been found to be vital for successful implementation as a low-cost alternative to ready-made calibrators. First, the laser power must be stable enough to allow a precise control of the echo characteristics. Our results are quite promising in this respect. Figure 10 shows the behavior of the temperature controller over an arbitrary
observation time. We have been able to maintain 0.1 mK settability. Then, in Figure 11 we see that the optical output power is stable within some tenths of a dB thus allowing echo amplitude setting well better than 1 dB.

IF amplifier matching and gain performance remain challenges. We notice in the plot of Figure 12 that both multiple reflections caused by impedance mismatch (rapid fluctuations at 1-1.5 GHz) and the reduced net gain at lower frequencies (below 1 GHz) limit the available bandwidth. A target distance of 1 km has been selected for this measurement. However, for many real applications the region around 2 GHz (marked with the cursor) is very adequate. If more bandwidth is needed, some design effort must be devoted to the two RF/IF amplifiers.

REFERENCES

[1] R. Burns,
Radar Development to 1945,

[2] R.L. Ferranti,
Widgets and Wonders: Lincoln Laboratory's Unique Radar Hardware Legacy,

[3] D.K. Barton,
Radar System Analysis and Modeling,

Target Detection by Marine Radar,

[5] P. Eskenazi,
Introduction to RF Equipment and System Design,

[6] Phuong Phu, E. Adler, R. Ianicenti and A. Paolella,
A test target generator for wideband pulsed doppler radars,

[7] Edward I. Ackerman and Charles H. Cox,
RF fiber-optic link performance,

[8] Rajiv Ramaswami and Kumar N. Sivarajan,
Optical Networks - A Practical Perspective,

[9] Carl E. Wieman and Leo Hollberg,
Using diode lasers for atomic physics,

[10] K.G. Libbrecht and J.L. Hall,
A low-noise high-speed diode laser current controller,
Review of scientific instruments, Vol. 64, No. 8, 1993, pp. 2133-2135.

Instrumentation for the stable operation of laser diodes,
Practical Interfacing in the Laboratory
Using a PC for Instrumentation, Data Analysis and Control

Stephen E. Derenzo
Cambridge University Press, Cambridge, UK
2003, 610 pages, Hard cover
ISBN 0-521-81527-4

Lack of funding, personnel, and up-to-date instrumentation (compared to the continuously increasing number of students) have gradually decreased the amount of true electronics laboratory courses and exercises in technical universities. The availability of efficient and low-cost circuit simulation engines intended for PC environment have pushed much of the student-side activity of electronic and electrical engineering courses toward computer class work. As average students are rather familiar with PCs they tend to prefer such tasks and - if given some theoretical advice - often manage quite well. However, practical test and measurement skills are vanishing, many students within our field no more can use the soldering iron, oscilloscope, or spectrum analyzer and even some of the educators consider such projects as a waste of time and money. The problem has naturally been made worse by the fact that very few university-level textbooks or manuals are currently available for laboratory courses. The rapid advance in IC technology has turned some classic texts obsolete. Others are focused at proprietary hardware and associated PC licenses and are thus not independent. The wide scope of electronic laboratory work is certainly a challenge and many potential authors have withdrawn their proposals due to hard criticism or a feel of incompetence. New books don’t turn up often, therefore it is delightful to have a closer look at recent contributions to this field.

Our present review target, Practical Interfacing in the Laboratory, covers principal issues of analog and digital measurements and sensor control requiring PC interfacing. The first chapter discusses fundamental digital circuit blocks such as counters, registers, latches, and, of course, various data presentation formats. As a nice add-on, manual switch debounce is illustrated in detail. Analog circuits are the topic for Chapter 2. Here, we learn about operational amplifiers as gain blocks or filters and have a thorough treatment of their noise, power, and isolation characteristics. Conversions between the analog and digital worlds are treated in Chapter 3. Important issues like sampling frequency, aliasing, and resolution are covered. The reader gets a good view of various converter implementations as well. Physical interfaces toward the real world are shown in Chapter 4. This means various transducers for temperature, strain, force, motion (either linear or rotating), light, time and ionic potentials. The only real actuator concept that is briefly covered is a stepper motor (if we don’t count a heating resistor to be such) and, unfortunately, there is no laboratory project with it. Finally, Chapter 5 is a tutorial of data analysis methods for a PC environment. Typical tools include different mathematical processes to handle distributions, error estimations, and filters based on the Fourier transform and its relatives.

The author, Professor Stephen E. Derenzo, currently works in the Department of Electrical Engineering and Computer Sciences at University of California Berkeley. He is also a Senior Scientist at the Lawrence Berkeley National Laboratory. Professor Derenzo has authored more than 150 technical publications. He was awarded the 1992 Annual Merit Award and the 2001 Radiation Instrumentation Outstanding Achievement Award of the Nuclear and Plasma Sciences Society of the IEEE. Professor Derenzo is an IEEE Fellow. During the past 17 years, Professor Derenzo has been lecturing courses on electronic circuits, transducers, and microcomputer interfaces. It is therefore quite natural that the text in this book is a derivative of those educational packages. Most notably, his courses EEC 145L "Electronic Transducer Laboratory" and EEC 145M "Microcomputer Interfacing Laboratory" at Berkeley have brought practical, well-tested examples to the book. It is apparent that such a background is beneficial also when organizing material in book form - one certainly has an estimate about the needed amount of explanations and knows which parts of a specific project might create confusion or bottlenecks.

Within its 610 pages, Practical Interfacing in the Laboratory contains five main chapters and 27 practical laboratory exercises. Additional useful data is given in nine appendices and in a glossary containing about 500 definitions. There is an alphabetical index of roughly 900 words but no list of symbols is given. There are many equations, but, unfortunately, their numbering is not comprehensive at all, because only those expressions appearing in the main text are labeled with numbers. However, still more equations can be found in the worked examples and exercises - but no numbering has taken place here. Illustrations are used throughout the text in the form of circuit and block diagrams, pictures highlighting operating principles or physical phenomena and as plots of recorded data. The total number of pictures is approximately 370. Professor Derenzo has used 50 tables that give useful data of filter parameters, resistor and capacitor values, etc. A course instructor is given 130 ready-made problems. Solutions are available through the publisher, but naturally only for educational institutions.

This book is really intended for the laboratory environment. Every chapter has a suitable process description, then some numerical examples and a set of true experiments with physical devices. Many laboratory set-ups are built around a PC and its interface that can be a commercially available general purpose
I/O-card (in this case, DT3010 PCI) or an interface block suitable for Labview or HPVEE (e.g., an IEEE-488 card). In all cases C-programming is assumed. Practical examples cover simple LED control, switch position reading, A/D- and D/A-converters, pendulum motion registration and analysis, biomedical measurements (heart, muscles), voice sampling and processing, and temperature control with the PC. Some projects are relatively straightforward in nature while others require more time and patience. In every case very detailed instructions are given. The author indicates for every experiment the necessary items down to single resistors and shows step-by-step the construction of the test circuit and its functional verification. Pin numbers, connector types, and wire or cable selections are indicated very precisely. Even project report writing is “guided” in all tasks. Thus, if the tools, instruments, and components exist, students can be expected to carry out the laboratory measurements without additional supervision. Of course, the safety of people and equipment calls for the instructor to be present at all times.

Some parts of the text might have required further processing and, occasionally, the author has omitted topics that could have wide interest. The book does not contain an example or a project about a straight connection between one of the PC ports and a logic circuit built by the student. There is always a dedicated I/O card between. However, Chapter 1 does give adequate information about the most typical PC port standards. So, merely a suitable example is missing. The present form of discussion might yield to a situation where students consider interface construction too complicated to be performed "in house." Of course, the modern USB interface could have more attention nowadays instead of the RS-232 that has the longest description now, but, on the other hand, clarity and simplicity issues support author's decision. Real test equipment such as oscilloscopes, signal sources, and analyzers are not covered in detail. It seems that the author's own courses at Berkeley come after some basic electronics tutorials during which such topics are treated. However, this book might have included a summary of related material to the extent required by the practical laboratory tasks.

In fact, small items and details of Practical Interfacing in the Laboratory could be upgraded in coming editions. First of all, I can't see a reason why equations are not numbered in the exercises and projects. A similar concept to that used with illustrations could be used. Although the given examples and projects are applicable to a variety of interface cards, the author should have briefly mentioned other alternatives besides the DT3010. Most of the operational amplifier examples don't show the power supply voltages or their connection pins. Therefore, there is no place to indicate the mandatory filtering capacitors either. Although this issue is later (in an appendix) explained verbally, it comes too late for the amplifier experiments. Also, the concept of isolation amplifiers in Section 2.4.2 looks a bit incomplete. Professor Derenzo mentions just two needs for isolation: large (dangerous) DC or mains (50 or 60 Hz) voltages at the amplifier output. I would have included a third important application — isolation of the input circuitry against effects due to load variations or "normal-level" but still unwanted voltages created to the amplifier output. It is true that the remedies given in this book can handle such difficulties but they may be oversized, too. This would have given reasons to discuss conventional op-amp circuit topologies in more depth.

Section 4.10.2 called "Modern Time Measurement" is very short and omits important topics such as triggering problems and even the basic time and frequency profile estimations. Frequency standards are mentioned, but the expressions used to define their purpose are very general in nature and don't give practical advice to laboratory work. GPS disciplined crystal oscillators are not included and there is no information about the most common test equipment crystal oscillator types (ovenized, digitally compensated, and so on) and their characteristics; the varying instrument warm-up times due to oscillator start-up have been neglected. This might have led to the idea of measuring temperature very accurately with a simple crystal and a counter connected to the PC. Something strange has happened in Appendix F in which the author explains the acquisition of waveforms with a digital oscilloscope. To me the text looks as if somebody else wrote it, not the author, so "loose" is the description. There is not a single word about scope triggering and the proper settings for the horizontal and vertical axes are supposed to be found by applying autoscale! An experienced instructor can naturally handle the situation and show the proper way to go. It is sad, indeed, that the valuable and unique C-code examples developed by the author are only given as listings on paper. Now students (and the instructor) must re-type everything and this surely causes multiple unnecessary errors. Maybe the publisher could make a CD available to those who have already purchased the book? The overall cost shouldn't be a major question here.

Practical Interfacing in the Laboratory is an interesting combination. The author has selected a suitable variety of projects and themes so different courses at other universities can find enough applicable experiments for their purposes. The cross-technical approach is here a clear benefit. If one is not interested in biomedical measurements, they can be skipped and more time and effort can be put, for instance, on optical sensors. This is not to say that the book contains everything. No book can do that. Professor Derenzo has found a reasonable compromise between scientific presentation and fluent practical use. High-quality illustrations and well-edited equations and tables are easy to follow. His text apparently does not try to be more than is really needed, there are no portions just to show how educated and experienced the author is but all elements have their proper meaning for the real laboratory work. In a couple of projects, somewhat more information might have been helpful, particularly about the use of test instrumentation. However, an instructor having sufficient professional background from the industry or governmental institutions can relatively easily cope with this matter. The statistical analysis part in Chapter 5 has also been adapted for this book and it is easy to imagine how students can efficiently make use of that material. Writing all this, I must confess that I was satisfied. Practical Interfacing in the Laboratory is a good book to start with in the laboratory. Its target audience is definitely close to third year university students. Both electrical and mechanical engineering departments should find the text suitable. An engineer out in the field can also use this text as some form of a handbook; particularly, if hands-on guidance on C-language base control of hardware is needed.

Reviewed by Pekka Eskelinen
Conference Report

Radar 2005 – A Resounding Success

By all measures RADAR 2005, held May 9 - 12, 2005, at the Marietta Crystal City Gateway Hotel, Arlington, Virginia, USA, was the very best in the continuing series of the IEEE International RADAR Conferences held every 5 years in the Washington, DC area since 1975.

RADAR 2005 had approximately 600 attendees who took advantage of the 181 Technical Papers, 15 Tutorials, and 32 Exhibits. Each Tutorial was given twice by leading experts and included entry level, intermediate, and advanced tutorials. Continuing Education Credits were awarded upon completion. The 32 exhibits doubled the number of exhibitors in 2000. There were planned tours to the new Smithsonian Air and Space Annex near Dulles Airport, and the Historical RADAR Engineering Museum at the BWI Airport coupled with the National Cryptological Museum near Ft. Meade.

The attendees were split roughly equally between IEEE members and non-members and included 12 life members, 9 retired members, and a record 53 student members. Thirty of the fifty-three student members were international. Of the regular International Attendees there were 24 countries represented with the UK (27), Canada (12), China (11), Italy (11), Sweden (11), and Germany (10) having the most. Seven attendees took advantage of receiving a free section of their choice by joining IEEE at RADAR 2005.

General Chairman Thomas L. Fagan surprised the attendees at the Wednesday night Banquet by reading a Greeting from President George W. Bush welcoming all of the attendees to the IEEE International RADAR Conference (Figures 1A and 1B).

RADAR 2005 attracted the most students ever, with 53 attending from 13 countries. Many students submitted a paper for the Poster Session and there was a competition for the Best Student Paper which was won by Igal Bilak from Ben-Gurion University of the Negev, Israel (See Figure 2). RADAR 2005 was greatly indebted to the Army Research Office (ARO) and the Office of Naval Research (ONR) for proving grant funding to support student’s travel and living.

As in previous years, the IEEE Aerospace and Electronic Systems Society, the Northern Virginia Section, and the Washington Section hosted this conference along with the Institute of Electrical Engineers – UK as an Associate Sponsor.

Attendees also had the opportunity to avail themselves of vast research material in the Fred Nathanson Memorial Study Center. The center, named after early radar pioneer Fred Nathanson, featured a library of radar books, along with a copier, comfortable reading chairs, and plenty of complimentary coffee. Fred was a Fellow of the IEEE and

Fig. 1A. General Chair, Thomas L. Fagan

spent the early part of his radar career at Johns Hopkins University – Applied Physics Laboratory.

The Conference opened with a welcome by the Conference Chair, Tom Fagan. This was Tom’s third, and final year as General Chairman. Tom’s remarks were followed by short videos of RADAR leaders from supporting countries around the world welcoming the attendees. Then, Dr. Taylor Lawrence of Northrop Grumman chaired an excellent Keynote Session and Panel discussion on "The Future Directions in Spaced Based Radar."

Technical sessions included radar systems, components integration, radar data & signal processing, phenomenology, adaptive processing, tracking, synthetic aperture radar (SAR), antenna technology, simulation, and emerging technologies. Papers featured leading research by world renowned and rising young researchers and practitioners in the radar field.

Tutorials included: Introduction to Radar, Radar Cross Section, Electronically Scanned Radar Systems, Tracking and Kalman Filtering, SAR, Bistatic Radar, Space-based Radar,
I send greetings to those gathered for the International Radar Conference, hosted by the Institute of Electrical and Electronics Engineers.

Innovation continues to redefine the American workplace and is vital to our global economy. This event provides an opportunity for the world's leading specialists in radar systems and technology to share advances and opportunities in this important field. Through your work and commitment to excellence, IEEE members and all engineers expand the realm of the possible and contribute to global prosperity.

I appreciate IEEE members for supporting technological innovation in fields from computer engineering and biomedical technology to consumer electronics and aerospace engineering. By encouraging professional development and promoting high standards in engineering, you advance scientific endeavor and inspire the next generation of innovators.

Laura and I send our best wishes.

---

Radar for Automotive Applications, Radar Waveform Design, Radar Performance Modeling, and Clutter Modeling. Local IEEE Section members, Dr. Scott Goldstein and Dr. Mike Piccolo, both with SAIC in Virginia, double-teamed to deliver an informative tutorial on Space-Time Adaptive Processing (STAP) and Dr. Joe Guerci of DARPA presented an advanced tutorial on Knowledge-aided STAP. Overall, there were 544 Tutorial attendees with several attendees taking 2 and 3 tutorials.

At the Wednesday evening banquet, Dr. Muralidhar Rangaswamy, AFRL, a Senior Member of the IEEE, was presented the 2005 Nathanson Young Engineer Award for his work in non-Gaussian clutter modeling and adaptive signal processing, his extensive publications on radar research, and his support of numerous IEEE activities, including the IEEE Transactions on Aerospace and Electronic Systems (Figure 3). Mr. John Entzminger, Jr. was presented the Warren D. White Award for contributions to the art of RADAR engineering. Entzminger, IEEE Fellow, received the award:

"for his distinguished thirty-eight year career and leadership in Defense research and development in the critical areas of intelligence, surveillance,

---

Fig. 2. Igal Bilk, Ben-Gurion University of the Negev, winner of Student Paper Competition; Target Classification using Gaussian Mixture Model for Ground Surveillance Doppler Radar

---

Fig. 3. Muralidhar Rangaswamy receiving the Fred Nathanson Young Engineer of the Year Award from Mark Davis

reconnaissance, and targeting sensors" (Figure 4). [See also page 43, this issue.]

Major General George Harrison, Georgia Tech Research Institute, was the featured Banquet Speaker on the topic, "21st Century Radar – What Do Users Want?" (Figure 5).

Four IEEE Members elected to receive their Fellow Awards at the RADAR 2005 Banquet. These included:
Fig. 4. John Entzminger receiving the Warren D. White Award from Mark Davis

• William Gerard Bath,
  Johns Hopkins Applied Physics Lab

• Mark Edward Davis,
  AFRL

• James H. Michaels,
  AFRL

• James Ward,
  MIT Lincoln Laboratory

Fig. 5. Banquet Speaker MGen George Harrison


—Thomas L. Fagan
General Chair
FROM THE EDITOR-IN-CHIEF

Miscellany

FEEDBACK ON Systems Magazine REQUESTED — Well, you’ve had time to read and ponder last month’s issue of Systems. I hope some of you have sent feedback on the regular issue features, articles, tutorials, or the new featured article in the magazine’s centerfold.

If not, we would really like to hear from you. My goal is to provide an interesting, relevant, and quality publication for IEEE members and practitioners interested in AESS fields of interest. Hearing from you helps me steer Systems in a direction to meet that goal.

The preferred way to submit feedback to Systems is to go on-line at: <http://sysaes_msعد indicate.net> and submit your feedback as a “correspondence item.” This allows your feedback to be addressed in a timely manner by me or one of the other Systems Editors when I am not available. If you are not familiar with the on-line system, guidelines can be found at the top of our review system homepage under “Information to Authors.”

NEW IEEE EXECUTIVE DIRECTOR ANNOUNCED —
Following an extensive search, Jeffrey W. Raynes, CAE, has been selected for the position of IEEE executive director. Raynes, 51, will assume the position in November 2005. He will serve as chief operating officer and will manage the IEEE staff organization, which consists of approximately 900 employees. Additional information is available in the IEEE Newsroom: <http://www.ieee.org/portal/pages/newsinfo/newsinfo.html>.

IEEE SECTIONS CONGRESS 2005 — On 14-17 October 2005, at the Tampa Marriott Waterside Hotel, in Tampa, Florida, USA, IEEE will convene a Sections Congress. IEEE Sections Congress is a triennial gathering of Section leadership sponsored by the IEEE Regional Activities Board. An event which includes four days of working sessions and networking, Sections Congress involves hundreds of delegates from all ten Regions. Sections Congress is the one major meeting sponsored by IEEE which brings together the Institute’s grassroots leadership to share ideas, concerns, and solutions. The Congress is also a forum where Section Chairs speak as the collective voice of IEEE membership, expressing ideas about how the Institute can better serve its members, both now and going forward. The issues generated at Sections Congress have had a major impact on the plans made by IEEE leadership for the future of the Institute. The theme of Sections Congress 2005 is Promoting a World-Class Volunteer Community. For more information, go to the Sections Congress website: <www.ieee.org/sc2005>.

FULL-YEAR MEMBERSHIPS RETURN AFTER AUGUST 15 — The 2005 half-year membership period ended this year on August 15. Paper applications received after August 15 are being processed beginning in September at the 2006 full-year dues. Pricing for the on-line membership application is handled automatically based on the date the application form is completed. Applications which were completed on August 31 or after will receive a full-year 2006 Membership at the prevailing full-year rates.

On that note, the change back to full-year membership makes September an excellent time for recruiting new members. Not only is it a good prospecting time, as potential members are returning to school or work from summer vacations in many parts of the world; these new members will get up to an additional four months added to their membership. In other words, although they are joining — and paying — for the calendar year 2006, their membership actually becomes effective the moment they join. As a result, any months remaining in 2005 are an “added bonus.” “Pay for 12 months, get up to 16!” Even the rapidly disappearing “baker’s dozen” isn’t as good a deal.

HELP RECOGNIZE OUTSTANDING IEEE VOLUNTEERS — You can recognize the efforts of outstanding volunteers by nominating a deserving individual for one of the prestigious IEEE Regional Activities Board (RAB) awards! Each award has a unique mission and criteria and offers the opportunity to honor distinguished colleagues, inspiring teachers, and corporate leaders.

Do you know someone who has made substantial Regional contributions through innovative projects, exemplary leadership, service, or by fulfilling the goals as related to Transnational Activities? Consider nominating someone for one of the following awards:

- RAB Achievement Award
- RAB GOLD (Graduates of the Last Decade) Achievement Award
- RAB Innovation Award
- RAB Leadership Award
- RAB Larry K. Wilson Transnational Award

These are not technical achievement awards. The deadline for nominations is 15 October 2005. More information and nomination forms are available at the RAB Awards website.

— Evelyn Hirt

Congratulations!

We extend our congratulations to these new Senior Members (as of June 2005).

<table>
<thead>
<tr>
<th>Name</th>
<th>Section</th>
<th>Name</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peter D. Hanlon</td>
<td>Mid-Hudson</td>
<td>Robert D. McCarthy</td>
<td>Buenaventura</td>
</tr>
<tr>
<td>E.F. Charles LaBarge</td>
<td>Baltimore</td>
<td>Fang Po He</td>
<td>South Australia</td>
</tr>
<tr>
<td>Darin T. Dunham</td>
<td>Richmond</td>
<td>Heung-Sik Tae</td>
<td>Seoul</td>
</tr>
</tbody>
</table>

IEEE A&E SYSTEMS MAGAZINE, SEPTEMBER 2005
You are invited to Attend

2005 IEEE International Conference on Systems, Man, and Cybernetics

October 10-12, 2005, The Big Island, Hawaii, USA

SMC 2005 will provide a world-class forum for all aspects of systems engineering, human-machine systems, and emerging cybernetics. In recent years a trend has emerged in which complex systems are being integrated on a large scale with other self-contained systems to satisfy global objectives. Interoperability of resulting systems is enabled through information exchange and increased levels of automation. In light of this trend, the theme for the conference is the emerging discipline of Systems of Systems Engineering.

Papers are related to this theme, including theories, methodologies, and application of intelligent systems in science, technology, security, education, etcetera.

Topics covered include:

- Systems Modeling & Control
- Policy & Decision Support Systems
- Intelligent Transportation Systems
- Petri Nets & Discrete Event Systems
- Image Processing/PATTERN Recognition
- Multiagent Systems & Distributed AI
- Safety, Reliability & Quality Assurance
- Manufacturing Systems
- Systems Engineering Education
- Technology Assessment
- Internet/Electronic Commerce
- Data Mining & Management
- Large-Scale Systems
- Intelligent Communications
- Robotic Systems
- Human/Machine Systems
- Intelligent Systems
- Soft Computing
- Fuzzy Logic Systems
- Computational Intelligence
- Knowledge-based Systems

Conference Web Site: http://ieeesmc2005.unm.edu
**NASA Medal to John A. Reagan**

John A. Reagan (M '72, SM '83, F '88) has been awarded the NASA Distinguished Public Service Medal for:

Outstanding contributions to the advancement of active and passive atmospheric optical remote sensing techniques, which are critical toward understanding the optical properties of aerosols and their impact on the climate.

The NASA medal is awarded only to individuals:

Whose distinguished accomplishments contributed substantially to the NASA mission. The contributor must be so extraordinary that other forms of recognition would be inadequate.

**Professor Reagan** [BS(Phys), MS(EE), PhD(EE); University of Arizona] is an internationally recognized authority on LIDAR (Light Detection And Ranging); he contributed to the LIDAR development for NASA’s CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), launched in July 2005. He previously contributed to the LITE (Lidar In-space Technology Experiment), among others, and participated in a NASA Group Achievement Award as a Science Team Member of Space Shuttle Mission STS-64 LITE in 1965.

IEEE sponsored the 2005 Remote Sensing of Atmospheric Aerosols Workshop in his honor. Reagan has been extremely active in the IEEE Geoscience and Remote Sensing Society (GRSS) and a multitude of IEEE volunteer positions. His Fellow award was:

*For accomplishments in lidar and solar radiometric atmospheric sensing and contributions to electrical engineering education.*

He established the Atmospheric Remote Sensing Laboratory at the University of Arizona, was MIT's Distinguished Lecturer in 1996, is a member of Tau Beta Pi, Sigma Pi Sigma, Phi Kappa Phi, and is a registered Professional Engineer.
“Radar ...Our Sight Into a Spectrum of Information,” Highlights the Connection Between Radar and Information. This Theme Provides an Interesting Perspective to Consider the Increasingly Wider Spectrum of Target and Environmental Information that has Evolved, Far Beyond the Original Capability to Detect the Target and Determine its Range, from Innovative Radar Research, Technology, and Component Development, for both Military and Civilian Applications.

For more information visit www.radar06.org
John N. Entzminger, Jr.

one of the trio receiving
the IEEE AESS Pioneer Award
for 1998

For pioneering efforts in basic concepts,
system designs and technical ideas that
led to a major new US military capability;
the Joint Surveillance and Target
Attack Radar System of Joint STARS.

was presented with the 2005
Warren D. White Award
for Excellence in Radar Engineering
during the 2000 Radar Conference.

John N. Entzminger, Jr. (S’57–M’59–SM’76–F’81) was born in Memphis, TN. He received his B.S. (Magna Cum Laude) in Electrical Engineering from the University of South Carolina in 1959, and M.S.E.E. from Syracuse University, Syracuse, NY in 1968.

From 1969-1973, he was the Chief of the Advanced Location and Control Section in the Communications and Control Division of Rome Air Development Center (RADC), Rome, NY where he was responsible for exploratory engineering development in the location and identification of electronic emitters; guidance and control of standoff weapons; anti-jam, multiple access TDMA satellite communications; and Loran and DME navigation. From 1973-1981, Mr. Entzminger was the Chief of the Location and Control Branch of the Communications and Control Division where he directed several high visibility programs in long range radar detection, location and attack of MTI targets, real time precision location, and attack of emitters, standoff weapon guidance and control, and Jam resistant communication programs.

From 1983-1991, Mr. Entzminger was the Director of the Tactical Technology Office in the Defense Advanced Research Projects Agency (DARPA) where he planned, directed, and managed air defense, close combat land warfare, deep battle interdiction, special operations, command & control, and intelligence, anti-submarine warfare, and advanced aircraft aerodynamics. From 1991–1993, he was the Chief of Advanced Technology programs at DARPA where he was responsible for providing advice to the Director on science, technology, and the formulation and management of advanced technology programs. In this capacity he also served on the Defense Science Board and on a joint duty assignment with the National Reconnaissance Office. From 1994-1995, he worked as Director of the DARPA High Altitude Endurance (HAE) Unmanned Aerial Vehicle Joint Program Office where he managed joint Air Force and Navy HAE unmanned air vehicle developments.

From 1996 to 1998, Mr. Entzminger was the Deputy for Technology for the Defense Airborne Reconnaissance Office (DARO). In this role he provided leadership and oversight to joint service developments in advanced EO/IR/SAR/video sensors programs. In July 1997, he was appointed to chair an airborne radar study to explore technical issues in future MTI/SAR radar systems.

Mr. Entzminger has published several papers on radar systems and communications in the areas of Precision Strike, and the detection, location and recognition of ground targets. He has one patent on a Coherent Frequency Hop Phase-Modulated Acoustic Surface Wave Generator, issued in 1969. He has received several awards and commendations including the Air force Outstanding Civilian Service Award (1974), the RADC Harry I. Davis Award for Outstanding Technical Achievement (1978), eleven US Senior Executive Service Outstanding Performance Awards, the Secretary of Defense Medal for Meritorious Civilian Service (1995), the Aviation Week Laurels Award for Outstanding Achievement in the Field of Unmanned Aerial Vehicle Reconnaissance Systems (1995), and the Association for Unmanned Vehicle Systems International (AUVSI) Pioneer Award for Outstanding accomplishments. He is a senior member of AIAA.
# Distinguished Lecturers Program

*James R. Huddle, Chairman*

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 AES, 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.

<table>
<thead>
<tr>
<th>Title</th>
<th>Name</th>
<th>Contact Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Control Technology Applied to Aircraft &amp; Automobiles</td>
<td>Dr. Kimio Kanai, <em>National Defense Academy of Japan</em></td>
<td>814-458-1244 (V&amp;F)</td>
</tr>
<tr>
<td>Avionics for Manned Spacecraft</td>
<td>Dr. Myron Kayton, <em>Kayton Engineering Co.</em></td>
<td>(310) 393-1819</td>
</tr>
<tr>
<td>Evolution of Aircraft Avionics</td>
<td></td>
<td>(310) 393-1261 F</td>
</tr>
<tr>
<td>Navigation: Land, Sea, Air and Space</td>
<td></td>
<td><a href="mailto:m.kayton@ieee.org">m.kayton@ieee.org</a></td>
</tr>
<tr>
<td>One Hundred Years of Inertial Navigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practitioner’s View of System Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthetic Aperture Radar</td>
<td></td>
<td>+44-20-7388-7325 F</td>
</tr>
<tr>
<td>Current Advances in Radar Technology</td>
<td>Robert T. Hill, Consultant and Lecturer</td>
<td>(301) 262-8792 (V&amp;F)</td>
</tr>
<tr>
<td>Evolution of Inertial Navigation</td>
<td>Dr. Itzhack Bar-Itzhack</td>
<td>+972-4-829-3196</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+972-4-829-2030 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:baritz@technion.ac.il">baritz@technion.ac.il</a></td>
</tr>
<tr>
<td>Formal Methods in System Design</td>
<td>Dr. James F. Peters, <em>Univ. of Manitoba</em></td>
<td>(204) 474-7419</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:jrpeters@ee.umanitoba.ca">jrpeters@ee.umanitoba.ca</a></td>
</tr>
<tr>
<td>Multisensor Data Fusion</td>
<td>Dr. Pramod Varshney, <em>Syracuse University</em></td>
<td>(315) 463-2266</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(315) 463-8261 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:Dick.Wiley@aol.com">Dick.Wiley@aol.com</a></td>
</tr>
<tr>
<td>National Missile Defense and Early Warning Radars</td>
<td>Larry Chasteen, <em>University of Texas at Dallas</em></td>
<td>(972) 234-3170</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(972) 883-2799 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:chasteen@utdallas.edu">chasteen@utdallas.edu</a></td>
</tr>
<tr>
<td>Novel Orbits &amp; Satellite Constellations</td>
<td>Dr. Daniele Mortari, <em>Texas A&amp;M University</em></td>
<td>(979) 845-0734</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(979) 845-6051 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:mortari@aero.tamu.edu">mortari@aero.tamu.edu</a></td>
</tr>
<tr>
<td>Planetary Exploration with Spacecraft — to Jupiter, Saturn, Uranus, Neptune and Beyond</td>
<td>Dr. William W. Ward, Consultant &amp; Lecturer</td>
<td>(617) 527-5331 (V&amp;F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://www.ward@ieee.org">www.ward@ieee.org</a></td>
</tr>
<tr>
<td>Radar — Past, Present and Future</td>
<td>Dr. Eli Brookner, <em>Raytheon</em></td>
<td>(978) 440-4007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(978) 440-4040 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:Eli_Brookner@res.raytheon.com">Eli_Brookner@res.raytheon.com</a></td>
</tr>
<tr>
<td>Satellite Communication Systems</td>
<td>Dr. S.H. Durrani, <em>Consulting Engineer</em></td>
<td>(301) 774-4007 (V&amp;F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.durrani@ ieee.org</td>
</tr>
<tr>
<td>System Engineering for International Development</td>
<td>Paul Gartz, <em>Boeing Co.</em></td>
<td>(206) 954-9616</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:p.gartz@ieee.org">p.gartz@ieee.org</a></td>
</tr>
<tr>
<td>Target Tracking and Data Fusion: How to Get the Most Out of Your Sensors</td>
<td>Dr. Yaakov Bar-Shalom, <em>Univ. of Connecticut</em></td>
<td>(806) 486-4823</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(806) 486-2285 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:ybsh@enr.uconn.edu">ybsh@enr.uconn.edu</a></td>
</tr>
</tbody>
</table>

All data on this page is under the purview of James Howard, VP-Member Affairs. Please send all corrections and omissions to him at the address on the inside back cover.
IEEE ION®
Co-sponsored by the IEEE and The Institute of Navigation®

TECHNICAL MEETING
April 25–27, 2006
Tutorials: April 24

Program Committee
Chuck Bye, Honeywell
General Chair
Wayne Soehren, Honeywell
Technical Program Chair
Dr. Frank van Graas, Ohio University
Technical Program Co-chair

Further details at www.plans2006.org

*In March 2005, the IEEE and the ION® entered into an agreement whereby both organizations would equally sponsor and support the technical program and conference management of the PLANS 2006 conference. As part of the agreement, the PLANS 2006 conference will replace the ION's annual summer meeting. The ION's annual awards and Fellow awards, which are typically awarded during the ION's summer meeting, will be awarded during the course of PLANS 2006. We invite you to participate in the joint IEEE/ION® meeting with exciting new opportunities for technical exchange and networking.

PLANS 2006
POSITION LOCATION AND NAVIGATION SYMPOSIUM

The IEEE and the ION® are hosting PLANS together in 2006!

Loews Coronado Bay Resort, San Diego

Coronado (San Diego), California

Further details at www.plans2006.org

Abstracts Due November 15, 2005!

Abstract Submission
Please submit all abstracts via the PLANS Web site no later than November 15, 2005. There are two ways to submit an abstract: 1) Go to www.plans2006.org, and click on the abstract submission link; or 2) abstracts may be e-mailed to abstractsubmission@ion.org as a Microsoft Word or text file. Be sure to include the paper title, the most appropriate session topic for the paper, a list of all authors and affiliations, and the primary contact author's complete mailing address, phone, fax and e-mail. Abstracts should be limited to 300 words and should describe objectives, results, conclusions and the significance of your work.

Abstracts will be acknowledged electronically. Abstract title and corresponding primary author will be posted weekly on the PLANS Web site. If your name does not appear after two weeks, please call the Institute of Navigation National Office at (703) 383-9688. Authors will be notified of acceptance in December and sent an electronic author's kit with presentation and publication guidelines. Papers will be published in the public domain. Classified or ITAR restricted abstracts and papers will not be accepted.

All presenting authors will receive an author discount on registration fees.

Final Manuscripts
Final manuscripts are due at the ION® National Office by April 3, 2006. Revised papers will not be accepted after May 5, 2006.
### IEEE AEROSPACE AND ELECTRONIC SYSTEMS SOCIETY CHAPTERS

All information on this page is obtained directly from the IEEE Master Data Base. If there are errors, the information entered is incorrect; it is not possible for this publication to make changes until and unless data is corrected, added to, or deleted. Access for correction of this data is available for authorized individuals through the RAB - Regional Activities Board - section of the IEEE website; http://www.ieee.org.

#### CHAPTER CHAIRS

<table>
<thead>
<tr>
<th>REGION 1 — Northeastern USA</th>
<th>Eli Brooker</th>
<th>Lexington, MA</th>
<th><a href="mailto:ebrooker@lexraytheon.com">ebrooker@lexraytheon.com</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Central New England Council</td>
<td>Jefferson Brownfield</td>
<td>Binghamton, NY</td>
<td><a href="mailto:jbrownfield@ieee.org">jbrownfield@ieee.org</a></td>
</tr>
<tr>
<td>Connecticut, <a href="http://www.iewebe.org/ct/ct/conn">http://www.iewebe.org/ct/ct/conn</a></td>
<td>Theodoros S. Saunders</td>
<td>Hanover, NH</td>
<td><a href="mailto:theo@sunoptics.com">theo@sunoptics.com</a></td>
</tr>
<tr>
<td>Mohawk Valley, <a href="http://www.iewebe.org/mohawk_valley">http://www.iewebe.org/mohawk_valley</a></td>
<td>Vincent C. Vannicola</td>
<td>Burnsville, MN</td>
<td><a href="mailto:vvanncola@amric.com">vvanncola@amric.com</a></td>
</tr>
<tr>
<td>New Jersey Coast, <a href="http://www.iewebe.org/nj/coast">http://www.iewebe.org/nj/coast</a></td>
<td>William J. Baldwin, Jr.</td>
<td>Center, NY</td>
<td><a href="mailto:buhlygov@ieee.org">buhlygov@ieee.org</a></td>
</tr>
<tr>
<td>Rochester, <a href="http://www.iewebe.org/roch">http://www.iewebe.org/roch</a></td>
<td>Dr. Reynolds</td>
<td>Ocean Grove, NJ</td>
<td><a href="mailto:dr.reynolds@ieee.org">dr.reynolds@ieee.org</a></td>
</tr>
<tr>
<td>Syracuse, <a href="http://www.iewebe.org/syracuse">http://www.iewebe.org/syracuse</a></td>
<td>Fred C. Kettlerman</td>
<td>Webster, NY</td>
<td><a href="mailto:feckettlerman@rochester.com">feckettlerman@rochester.com</a></td>
</tr>
<tr>
<td>—</td>
<td>Bin Chen</td>
<td>Syracuse, NY</td>
<td><a href="mailto:sacc@syr.edu">sacc@syr.edu</a></td>
</tr>
<tr>
<td>—</td>
<td>Lisa Ann Osofsky</td>
<td>Syracuse, NY</td>
<td><a href="mailto:lisa.o.ofsky@nco.com">lisa.o.ofsky@nco.com</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 2 — Eastern USA</th>
<th>William B. Dixon</th>
<th>Glen Burnie, MD</th>
<th><a href="mailto:w.dixon@ieee.org">w.dixon@ieee.org</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore, <a href="http://www.iewebe.org/baltimore">http://www.iewebe.org/baltimore</a></td>
<td>Vincent R. Lalli</td>
<td>Cleveland, OH</td>
<td><a href="mailto:vincrlalli@ieee.org">vincrlalli@ieee.org</a></td>
</tr>
<tr>
<td>Cleveland, <a href="http://www.ieeecleveland.org">http://www.ieeecleveland.org</a></td>
<td>Roger R. Oliva</td>
<td>Fultana, VA</td>
<td><a href="mailto:rogoliva@ieee.org">rogoliva@ieee.org</a></td>
</tr>
<tr>
<td>Northern Virginia, <a href="http://www.iewebe.org/2/ncs_virginia">http://www.iewebe.org/2/ncs_virginia</a></td>
<td>John S. Sadak</td>
<td>Delran, NJ</td>
<td><a href="mailto:john.s.sadak@ieee.org">john.s.sadak@ieee.org</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 3 — Southeastern USA</th>
<th>Gerg A. Showman</th>
<th>Marietta, GA</th>
<th><a href="mailto:gerg.showman@gru.gan.edu">gerg.showman@gru.gan.edu</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta, <a href="http://www.ieeecs.org">http://www.ieeecs.org</a></td>
<td>Charles H. Chapman</td>
<td>Merritt Island, FL</td>
<td><a href="mailto:cchm@bellhaven.net">cchm@bellhaven.net</a></td>
</tr>
<tr>
<td>Canaveral, <a href="http://www.iewebe.org/cec/canaveral">http://www.iewebe.org/cec/canaveral</a></td>
<td>James S. Lummis</td>
<td>Normal, AL</td>
<td><a href="mailto:jhumim@ieee.org">jhumim@ieee.org</a></td>
</tr>
<tr>
<td>Florida West Coast,</td>
<td>William T. Bishop</td>
<td>Huntsville, AL</td>
<td><a href="mailto:william.bishop@us.army.mil">william.bishop@us.army.mil</a></td>
</tr>
<tr>
<td><a href="http://www.iewebe.org/3/florida">http://www.iewebe.org/3/florida</a></td>
<td>David E. Finschaugh</td>
<td>Orlando, FL</td>
<td><a href="mailto:davidlfinsch@lor.com">davidlfinsch@lor.com</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 4 — Central USA</th>
<th>Robert G. Desoff</th>
<th>Plymouth, MI</th>
<th><a href="mailto:r.desoff@ieee.org">r.desoff@ieee.org</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Michigan, <a href="http://www.ieeemichigan.org">http://www.ieeemichigan.org</a></td>
<td>Ferrouz Sadiq</td>
<td>Minneapolis, MN</td>
<td><a href="mailto:sadiq@uiw.edu">sadiq@uiw.edu</a></td>
</tr>
<tr>
<td>Twin Cities</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 5 — Southwestern USA</th>
<th>Tim D. Reichard</th>
<th>Dallas, TX</th>
<th><a href="mailto:time@chord.com">time@chord.com</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas, <a href="http://engineering.ucla.edu/IEEE/IEEEindex.html">http://engineering.ucla.edu/IEEE/IEEEindex.html</a></td>
<td>Stephen M. Papa</td>
<td>Fort Worth, TX</td>
<td><a href="mailto:stephen.m.papa@lnco.com">stephen.m.papa@lnco.com</a></td>
</tr>
<tr>
<td>Fort Worth, <a href="http://www.iewebe.org/3/fort_worth">http://www.iewebe.org/3/fort_worth</a></td>
<td>S. Zafar Navi</td>
<td>Saginaw, TX</td>
<td><a href="mailto:svnavi@co.edu">svnavi@co.edu</a></td>
</tr>
<tr>
<td>Galveston Bay, <a href="http://www.gccc.com/catalog/">http://www.gccc.com/catalog/</a></td>
<td>Steve J. Delory</td>
<td>Colorado Springs, CO</td>
<td><a href="mailto:sjdelory@usa.com">sjdelory@usa.com</a></td>
</tr>
<tr>
<td>Colorado Springs, CO</td>
<td>James V. Leonard</td>
<td>St. Charles, MO</td>
<td><a href="mailto:jleonard@lee.org">jleonard@lee.org</a></td>
</tr>
<tr>
<td>Denver, <a href="http://www.iewebe.org/3/westcoast">http://www.iewebe.org/3/westcoast</a></td>
<td>George R. Dean</td>
<td>Wichita, KS</td>
<td><a href="mailto:g.dean@hsbn.com">g.dean@hsbn.com</a></td>
</tr>
<tr>
<td>Kansas City, <a href="http://www.ieecom.org">http://www.ieecom.org</a></td>
<td>D. Balakrishnan</td>
<td>Student Chapter</td>
<td></td>
</tr>
<tr>
<td>University of Missouri-Rolla, <a href="http://www.ece.unr.edu/~ieeecsb">http://www.ece.unr.edu/~ieeecsb</a></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 6 — Western USA</th>
<th>Mahendra Mallick</th>
<th>San Diego, CA</th>
<th><a href="mailto:mahendra.mallick@lnco.com">mahendra.mallick@lnco.com</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>San Diego, <a href="http://www.ieeecsd.org">http://www.ieeecsd.org</a></td>
<td>Eric L. Gode</td>
<td>Redmond, WA</td>
<td><a href="mailto:eric.gode@boeing.com">eric.gode@boeing.com</a></td>
</tr>
<tr>
<td>Seattle, <a href="http://www.ieeecseattle.org">http://www.ieeecseattle.org</a></td>
<td>James N. McNair</td>
<td></td>
<td><a href="mailto:mcnaaim@ece.pdx.edu">mcnaaim@ece.pdx.edu</a></td>
</tr>
<tr>
<td>Portland State University, <a href="http://www.ieee.or.org/studentbran">http://www.ieee.or.org/studentbran</a></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 7 — Canada</th>
<th>Reza Diazji</th>
<th>Waterloo, ON</th>
<th><a href="mailto:reza.diazji@raytheon.com">reza.diazji@raytheon.com</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchener-Waterloo</td>
<td>Melville Walker</td>
<td>Ottawa, ON</td>
<td><a href="mailto:metwalker@ig.net">metwalker@ig.net</a></td>
</tr>
<tr>
<td>Ottawa, <a href="http://members.aolstream.com">http://members.aolstream.com</a> Nº7/Enax-com/ottawa.AESS.html</td>
<td>Xavier Malague</td>
<td>Quebec City</td>
<td><a href="mailto:malagae@pct.ulaval.ca">malagae@pct.ulaval.ca</a></td>
</tr>
<tr>
<td>Toronto, <a href="http://www.iewebe.org/7/torontochapters/signals.htm">http://www.iewebe.org/7/torontochapters/signals.htm</a></td>
<td>Sridhar Krishnamoorthy</td>
<td>Toronto, ON</td>
<td><a href="mailto:sridhar.krishnamoorthy@cc.ece.yorku.ca">sridhar.krishnamoorthy@cc.ece.yorku.ca</a></td>
</tr>
<tr>
<td>Vancouver, <a href="http://www.iewebe.org/7/vancouver.html">http://www.iewebe.org/7/vancouver.html</a></td>
<td>Robert M. Leitch</td>
<td>Richmond, BC</td>
<td><a href="mailto:rleitch@ieee.org">rleitch@ieee.org</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 8 — Europe, Middle East, Africa</th>
<th>Gaspare Gatini</th>
<th>Rome, Italy</th>
<th><a href="mailto:galini@isp.uniroma1.it">galini@isp.uniroma1.it</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Central &amp; South Italy, <a href="http://www.ieee.org/italia">http://www.ieee.org/italia</a></td>
<td>Petru-Nicoi Tudor</td>
<td>Thessaloniki, Greece</td>
<td><a href="mailto:nicoi@vrginalia.ese.ind.in">nicoi@vrginalia.ese.ind.in</a></td>
</tr>
<tr>
<td>Israel, <a href="http://www.eng.tau.ac.il/ieee">http://www.eng.tau.ac.il/ieee</a></td>
<td>Nadav Levanon</td>
<td>Tel Aviv, Israel</td>
<td><a href="mailto:nadav@eng.tau.ac.il">nadav@eng.tau.ac.il</a></td>
</tr>
<tr>
<td>Poland, <a href="http://www.ru.polska.lee">http://www.ru.polska.lee</a></td>
<td>Michael F. Moskowicz</td>
<td>Gdansk, Poland</td>
<td><a href="mailto:mbrug@gdl.gda.pl">mbrug@gdl.gda.pl</a></td>
</tr>
<tr>
<td>Russia (Northwest)</td>
<td>Boris Levitas</td>
<td>Vilnius, Lithuania</td>
<td><a href="mailto:info@geona.com">info@geona.com</a></td>
</tr>
<tr>
<td>Spain, <a href="http://www.iewebe.org/8/spain/chapters.html">http://www.iewebe.org/8/spain/chapters.html</a></td>
<td>Yuri V. Filatov</td>
<td>St. Petersburg, Russia</td>
<td><a href="mailto:yurifiliatov@main.ru">yurifiliatov@main.ru</a></td>
</tr>
<tr>
<td>Turkey, <a href="http://www.iewebe.org/tur">http://www.iewebe.org/tur</a></td>
<td>Antonio A. Filatov-Fust</td>
<td>Simon's Town, South Africa</td>
<td><a href="mailto:phi@eng.uva.ac.za">phi@eng.uva.ac.za</a></td>
</tr>
<tr>
<td>Ukraine, <a href="http://www.ieee.org/ua/chapters.html">http://www.ieee.org/ua/chapters.html</a></td>
<td>Muriel B. Elia</td>
<td>Madrid, Spain</td>
<td><a href="mailto:aclfas@cnt.es">aclfas@cnt.es</a></td>
</tr>
<tr>
<td>United Kingdom &amp; Republic of Ireland, <a href="http://www.ieee.org.uk">http://www.ieee.org.uk</a></td>
<td>Antonio A. Kireenko</td>
<td>Ankara, Turkey</td>
<td><a href="mailto:efie@eng.adelaide.edu.au">efie@eng.adelaide.edu.au</a></td>
</tr>
<tr>
<td>United Kingdom &amp; Republic of Ireland, <a href="http://www.ieee.org">http://www.ieee.org</a></td>
<td>Hagh D. Griffiths</td>
<td>London, United Kingdom</td>
<td>h <a href="mailto:Griffiths@ieee.org">Griffiths@ieee.org</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 9 — Latin America</th>
<th>Sunjun Wu</th>
<th>Xian Shangxi, China</th>
<th>sjwu@cs uniforms.edu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing, <a href="http://www.ieee-beijing.org">http://www.ieee-beijing.org</a></td>
<td>Ram C. Gupta</td>
<td>New Delhi, India</td>
<td><a href="mailto:gcd@ieee.org">gcd@ieee.org</a></td>
</tr>
<tr>
<td>India Council, <a href="http://www.ieee.org/10/indiaouncil">http://www.ieee.org/10/indiaouncil</a></td>
<td>Yoshiaki Suzuki</td>
<td>Tokyo, Japan</td>
<td><a href="mailto:yosuzuki@nact.or.jp">yosuzuki@nact.or.jp</a></td>
</tr>
<tr>
<td>Japan Council</td>
<td>Chau G. Park</td>
<td>Seoul, Korea</td>
<td><a href="mailto:chau.park@smu.edu.kr">chau.park@smu.edu.kr</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGION 10 — Asia and Pacific</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing, <a href="http://www.ieee.org/10/section=Beijing">http://www.ieee.org/10/section=Beijing</a></td>
<td>Sunjun Wu</td>
<td>Xian Shangxi, China</td>
<td>sjwu@cs uniforms.edu</td>
</tr>
<tr>
<td>India Council, <a href="http://www.ieee.org/10/indiaouncil">http://www.ieee.org/10/indiaouncil</a></td>
<td>Ram C. Gupta</td>
<td>New Delhi, India</td>
<td><a href="mailto:gcd@ieee.org">gcd@ieee.org</a></td>
</tr>
<tr>
<td>Japan Council</td>
<td>Yoshiaki Suzuki</td>
<td>Tokyo, Japan</td>
<td><a href="mailto:yosuzuki@nact.or.jp">yosuzuki@nact.or.jp</a></td>
</tr>
<tr>
<td>South Australia, <a href="http://www.ieee.org/10/section=australia">http://www.ieee.org/10/section=australia</a></td>
<td>Mark B. Frechel</td>
<td>Salisbury, South Australia</td>
<td><a href="mailto:mark.frechel@data.defense.gov.au">mark.frechel@data.defense.gov.au</a></td>
</tr>
</tbody>
</table>
OFFICERS

President – Paul E. Gartz
Executive Vice President – James V. Leonard
Secretary – John R. Weyrauch
Treasurer – Charles H. Gager
Vice President - Administration – Robert N. Trebits
Vice President – Conferences – Barry C. Breen
Vice President – Education – Sajjad H. Duranri
Vice President – Member Affairs – James Howard
Vice President – Publications – Edward K. Reedy
Vice President – Technical Operations – James B. Huddle

ASSOCIATE OFFICERS

Associate Treasurer – Jose R. Bolanos
Associate VP – Administration – Open
Associate VP – Conferences – Irani J. Weinsten
Associate VP – Education – Open
Associate VP – Member Affairs – S. Zafar Taqvi
Associate VP – Publications – Joel F. Walker

BOARD OF GOVERNORS

Senior Past President — Paul J. Kostek
Junior Past President — Russell J. Lefevre

Members-at-Large

1/1/03 To 12/31/05
Evelyn H. Hirt
Theodora S. Sanders
James M. Rankin
Marina Ruggieri
Ronald L. Tucker
Robert N. Trebits
Irmak J. Weinstein
John R. Weyrauch

1/1/04 To 12/31/06
Walter D. Downing
Paul B. Gartz
J. Scott Goldstein
Hugh D. Griffiths
Philip Holmer
James V. Leonard
Taehee Takahashi
Peter K. Willcot

1/1/05 To 12/31/07
W. Dale Blair
Jose R. Bolanos
Barry C. Breen
Robert Lysons, Jr.
Robert C. Rassa
Cary R. Spitzer
S. Zafar Taqvi
Joel F. Walker

1/1/06 To 12/31/08
Ram Gopal Gupta
Evelyn H. Hirt
William Lyons
Ron T. Ogan
Robert N. Trebits
Irmak J. Weinstein
John R. Weyrauch
Shunjun Wu

STANDING COMMITTEES

Accomplishments Search – W. Cooper
Awards – Erwin C. Gangl
• M. Barry Carlton Award – W. Dale Blair
• Harry Rowe Minno Award – Ron Schurer
• Warren D. White Award – Mark Davis
• Pioneer Award – Erwin C. Gangl
• Judith Reznik IEEE Field Award – Erwin C. Gangl
Chapters – Ron T. Ogan
Constitution, Organization & Bylaws – Charles C. Gager
Distinguished Lecturers – James H. Huddle
Education – Sajjad H. Duranri
Strategic Planning – Paul F. Gartz
Fellow Evaluation – Fritz Steudel
Fellow Search – Elliott L. Axelband
History – Henry Oman
International Activities – Hugh D. Griffiths
Nominations – Russell J. Lefevre
Professional Activities – M. Cardinale
Public Relations – James R. Huddle
Publication Editors:
• Systems – Evelyn H. Hirt
• Transactions – W. Dale Blair
• Business – Jose R. Bolanos
• Administrative Editor – David B. Dobson
Social Implications – Technical – Open
Standards – Arnold M. Greenspan
Student Activities – Jose R. Bolanos
Transnational Activities – Hugh D. Griffiths, Chair

TECHNICAL PANELS

Formal Methods in System Design – J. J. Alpigini, Chair
Gyro and Accelerometer – R. K. Currey, Chair
Integrated Avionics Systems – G. T. Logan, Chair
Radar Systems – J. Day, Chair
Space Systems – M. Ruggieri, Chair
Systems Engineering (including Large-Scale Systems) – P. E. Gartz, Chair
Target Tracking & Sensor Fusion – W. D. Blair, Chair

IEEE/AESS Website: http://www.ceh.ieee.org/aes
Please send corrections or omissions for this page to the Secretary

IEEE A&E SYSTEMS MAGAZINE, SEPTEMBER 2005