Sādhanā, Vol. 17, Parts 3 & 4, September 1992, pp. 459–466. © Printed in India.

Optoelectronics in satellite designs

T K ALEX

Laboratory for Electro-Optics Systems, Indian Space Research Organisation, Peenya, Bangalore 560058, India

Abstract. Design of artificial satellites for communication, remote sensing and scientific investigations follows, at present, a fixed pattern based on existing and proven technologies and the requirements of payload or experiment within the constraints of weight, volume and power available. The advances in optoelectronic components and systems have opened up a new dimension in designing satellites of the future, incorporating new technologies. This paper deals with general satellite design concepts based on optoelectronic systems wherever applicable.

Keywords. Optoelectronics; satellite design; fibre-optics; smart structure.

1. Introduction

Design of spacecraft at present follows a regular pattern based on conventional proven subsystems. While the designs of unmanned spacecraft have followed compact and modular concepts based on physical and functional aspects, large manned space stations/vehicles mostly derive their design from aircraft configurations (Steward 1988). Advances in optoelectronic components and systems have opened up new vistas in the design and concepts of future satellite configurations.

Use of fibre-optics for missiles and launch vehicles has been extensively studied for military application. Data networking in spacecraft using fibre-optic local area networks (LAN) is a technology derived from communication networks. Todd (1988) discussed the use of fibre-optics in aircraft design, to replace 'fly-by-wire' systems. The emergence of a number of fibre-optic sensors (Culshaw & Dakin 1989) and fibre-optic communication systems and new optoelectronic components opens up the possibility of new satellite configurations. This paper highlights these new possibilities in different subsystems of satellites.

Although, at present, many of the configuration ideas cannot be implemented *in toto* owing to the non-availability of high reliability optoelectronic parts and subsystems, such systems will be available in the near future.

2. Scientific instruments

Satellites are used to conduct a number of scientific experiments and observations in the field of remote sensing for resources survey, meteorology and astrophysics.

Designers of scientific instruments will find applications for the new optoelectronic components and systems. Multispectral charge-coupled device (CCD) arrays, intensified CCDs and IR-CCDs will be used extensively for radiometric/imaging experiments. Advanced imaging systems in X-ray and gamma rays and optical interferometry using fibre-optic tethered telescope systems in orbit will be realizable. Advanced on-board data processing/storage systems using optoelectronic devices will enhance the capability of the experiments.

3. Communication networks

Communication systems within the satellites consist of signal acquisition system from sensors, cameras and scientific equipment for data multiplexing, formatting and transmission to ground stations. The satellites receive signals from ground for telecommand purposes. The other aspect of communication consists of relaying of signals received from ground or from other satellites (transponder). The introduction of fibre optics will essentially change the networks within spacecraft. The large space stations will use LAN for data communication and TV-network within the station. Various network schemes are being studied at present considering the requirement of bandwidth, number of nodes, allowable bit errors (BER) and redundancy (Todd 1987).

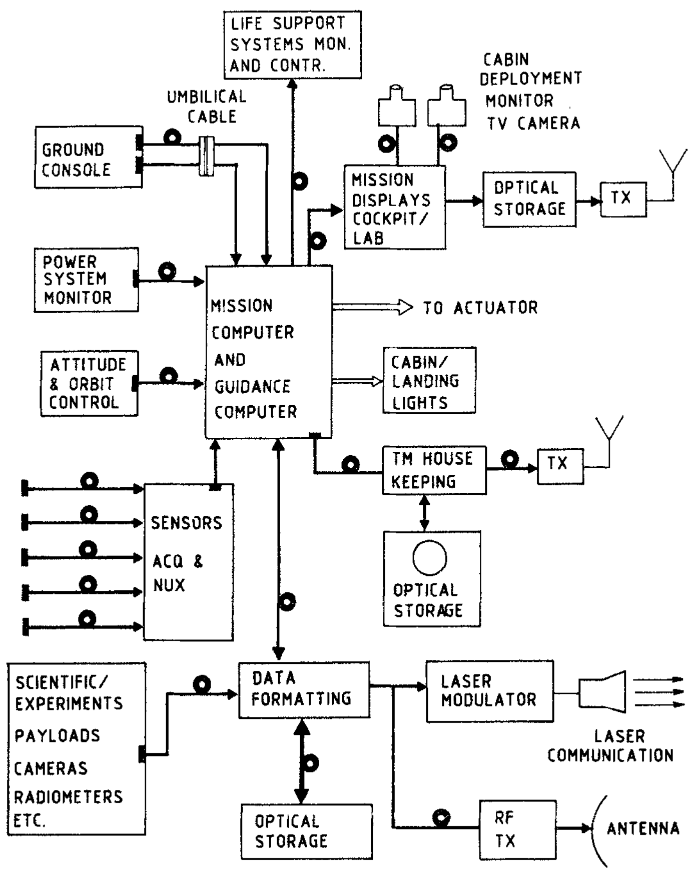

Figure 1. Fibre-optics in satellite integration.

The specification and identification of suitable topologies/protocols will be followed by the selection of appropriate optical fibres, nodes, laser diodes, detectors and connectors. Synchronous time division multiplexing, unidirectional and redundant ring and matrix networks are being considered (NAL 1987). These networks have specific advantages and limitations in terms of losses and signal-to-noise ratios compared to conventional electronic networks.

Small satellites will also benefit from advanced optoelectronics technology. High data rate systems including camera systems, radiometers and transmission systems can be interconnected using optical fibres. Spacecraft integration becomes simpler by reducing electromagnetic interference (EMI) between nearby cables and provides flexibility in locating various subsystems. The advantages in terms of EMI reduction have to be weighed against the requirements of additional connectors and devices. Figure 1 shows an overall block diagram of a fibre-optics network in a typical satellite configuration.

Optical communication using line-of-sight systems has limited application in ground systems. Such communication using lasers for satellite-to-satellite links for high data rates is practicable and can be realized in future. Geo-stationary Satellite Orbit (GSO) to GSO and Low Earth Orbit (LEO) to GSO links can be through laser systems. The main problems to be solved are the requirements of high power laser systems and high precision telescopes on satellites which need to track one another in the moving frames of references.

4. Power systems

Satellites essentially derive their electrical power from solar panels, and storage batteries are used for eclipse/peak load periods. Advanced solar cells like GaAs and Diamond-Like Carbon (DLC) will improve the efficiency of conversion of solar energy to electrical energy. Future large satellites will carry flexible roll-out panels with built in fibre-optic sensors for strain/deflection measurements and fibre-optic micro sun sensors (figure 2). Fibre-optic sensors will find application in current monitoring and remote bus monitoring and in protection systems, to avoid EMI. Opto-couplers will replace some inductive feedback elements in regulators and convertors to reduce switching transients. Large space stations will have high voltage power buses and efficient illumination systems, both inside and outside.

5. Attitude and orbit control systems

Optoelectronics finds new applications in attitude and orbit control systems. The directions of satellite axes in orbit are determined using various sensors like sun sensors, earth sensors and star sensors. These sensors will see improved performance by using better detectors and devices. Gyros are used to sense the orientation in the inertial reference frame. Mechanical gyros will be replaced by fibre-optic/ring laser gyros which will become standard packages in guidance systems. Fibre-optic nutation/acceleration sensors will be used for attitude manoeuvering operations. For missions involving docking with space stations, laser range sensors, CCD camera-aided range and attitude sensors will be important.

Fibre-optic sensors will find application in reaction control systems for monitoring

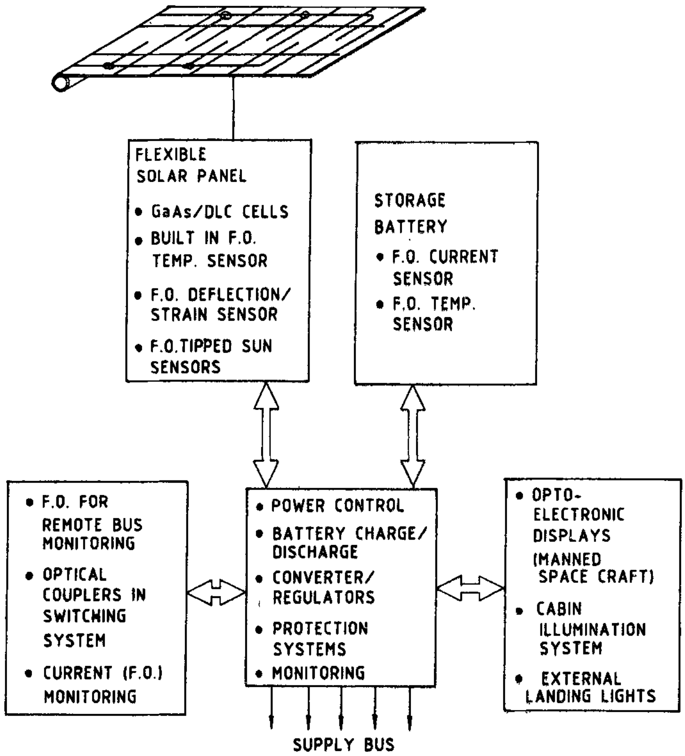

Figure 2. Optoelectronics in power systems.

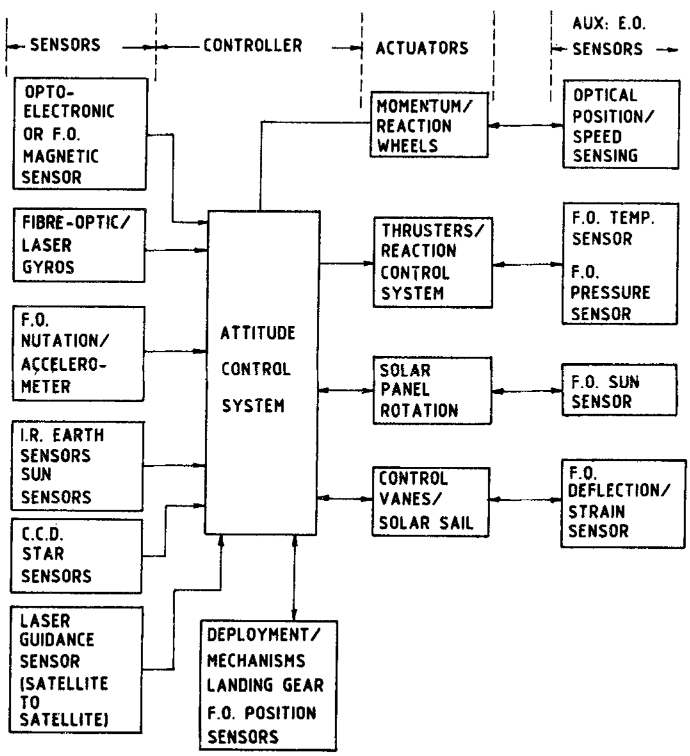

Figure 3. Optoelectronics in attitude control systems.

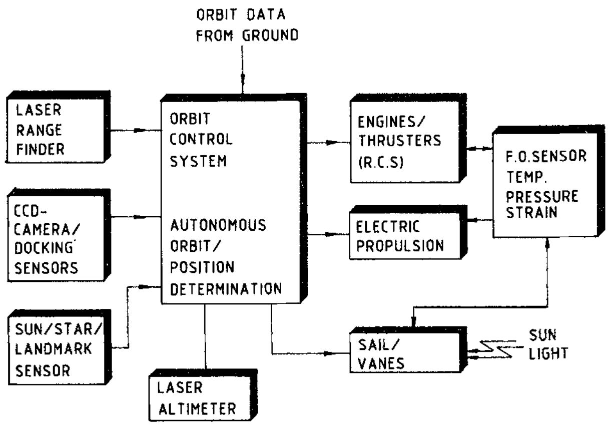

Figure 4. Autonomous orbit determination and control.

temperature and pressure of fuel, oxidizer and helium pressurant (Hocker 1979). Even in conventional subsystems like reaction/momentum wheels, optoelectronic devices will be used for angular position and speed sensing. Active control to counter the flexibility of the structure with the aid of an array of fibre-optic deflection sensors will be resorted to. Figure 3 shows an overview of the application of optoelectronics in attitude control systems.

In the area of autonomous orbit determination and guidance application where satellites find their own position in orbit, optoelectronic sensors will be used extensively. Laser altimeter, satellite-to-satellite range sensors and laser beacon tracking systems will be used. Figure 4 illustrates different possibilities of optoelectronics in this area. Autonomous navigation, using star and landmark sensors, will form standard packages for earth-orbiting satellites.

Optical computers are the latest in the area of computing systems. Fully optical or a hybrid of optical and electronic computers will be realized in the near future. Advances in computing speed using future optical computers or optical memory devices will find immediate application, in guidance and control systems (Todd 1988). They will enable fast computation for image processing in guidance sensors and also for parallel processing of data for optimal/adaptive control and fault-tolerant systems.

6. Structure and thermal control

Light weight structures and efficient thermal management systems are important aspects of satellite design. Future spacecraft, especially large space stations, allow large flexibility for the structure. Optoelectronics will facilitate new structural configuration by providing 'Smart Structures'. Monitoring of the dynamics of structural elements is required to control the flexibility and contain the structure–attitude control system coupling by active servo control. The carbon fibre structures will have optical fibres embedded in them for monitoring strain, deflection and temperature. Figure 5 summarizes some possibilities for structural configuration.

Future satellites will carry high resolution imaging camera systems and narrow-beam spot antennae which need high precision alignment of their axes and maintenance of the alignment with temperature changes. In-flight measurement of misalignment between various sensors and actuators, and measurement of structural deformation and thermal distortion will be realizable using new optoelectronic sensors.

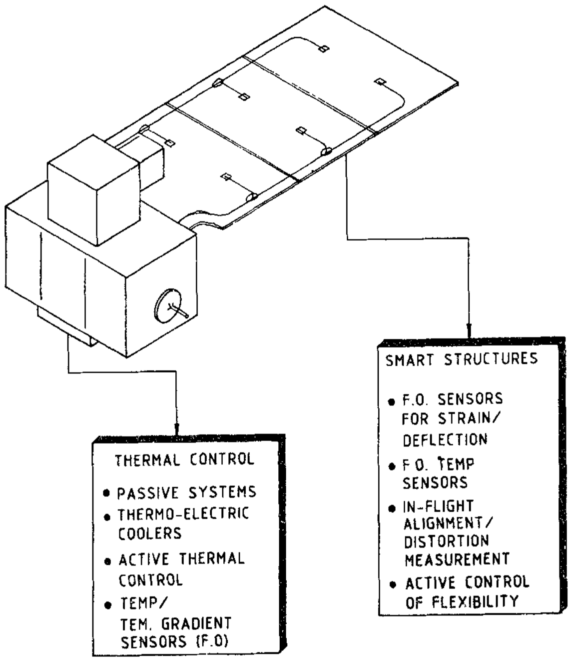

Figure 5. Smart structures and thermal control systems.

Fibre-optic sensors of reflective, micro-bend and resonant cavity types can be used for strain/deflection measurements (Buttler & Hocker 1978).

Thermal control systems will use a large number of fibre-optic temperature sensors. Depending upon the range and accuracy of measurement, sensors working on different principles like interferometry, black-body, Raman scatter or fluorescence, are potential candidates for temperature-sensing in future satellites.

7. Auxiliary systems

Satellites, especially large space stations, contain a number of auxiliary systems. Many of these systems already use optoelectronic devices. Advances in optoelectronics will enhance their capabilities. These include cabin illumination, on-board displays and video systems, optoelectronics for life support and medical equipment used in space.

8. Optoelectronics for ground systems

Optoelectronics finds applications in ground testing of the satellite systems autonomously and testing along with the launch vehicle on the launch pad. Fibre-optics finds application in umbilical cables which are used for monitoring and sending stimuli and telecommands and 'block-house to control centre' communication (figure 6). They are useful for data communication in environmental test facilities like space simulation, acoustic and vibration test facilities.

Satellite mission control is another area where advanced optoelectronic systems find immediate application. Besides fibre-optic data links between mission computer, mission control centre and telemetry and command stations, a number of novel display and large video systems will benefit from advances in optoelectronic technologies. The

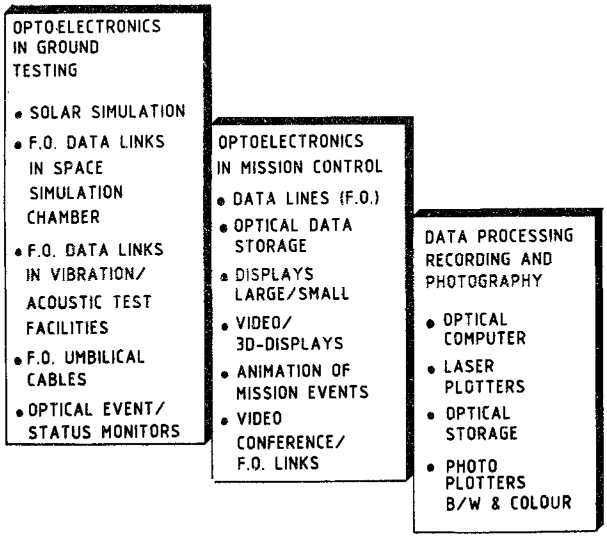

Figure 6. Optoelectronics in ground systems.

areas of data storage and data processing, especially for image processing, will be major tasks prior to data utilization. Optical data storage systems and optical computers, either fully optical or a hybrid of optics and electronics, will enable the handling of more data efficiently. Image processing of satellite data involves various processes like image formatting, contrast improvement, classification, pattern recognition and registration with auxiliary data. Many of these operations can be realized faster using optical computers.

9. Realization

This paper has described a number of possibilities of using new optoelectronic systems in satellites. Their realization on a large scale depends upon the availability of components and systems in space qualified version. Initially, total substitution becomes difficult. Wherever there is specific advantage in terms of reduced EMI, high data rate and reliability, the new optoelectronic devices, sensors and systems can be implemented.

10. Conclusion

The emerging technology of optoelectronics will revolutionize satellite systems and the approach to designs and configurations. The extent of these changes will be comparable to the revolution in electronics, instrumentation and satellite designs brought about by microprocessors, which began in the seventies and peaked in the last decade.

References

Buttler C D, Hocker G B 1978 Fibre-optic strain gauge. *Appl. Opt.* 17: 2867
Culshaw B and Dakin J 1989 *Optical fibre sensors* (Artech House)

Farali F *et al* 1988 Multiplexed sensing systems. *Proceedings of Fibre Optics Sensors III*, ECO/SPIE, vol. 1011
Hocker G B 1979 Fibre optic sensing of pressure and temperature. *Appl. Opt.* 18: 1445
NAL 1987 Optical computers – state of the art. *Proceedings of Symposium on Fibre-Optics Applications*
Steward R D 1988 Space platforms information distribution systems. *Proceeding of SPIE* vol. 989
Todd J R 1987 The role of fibre optics on commercial aircrafts. *Proceedings of SPIE* vol. 840
Todd J R 1988 Toward fly-by-light aircraft. *Proc. SPIE* vol. 989