esa bulletin

OTS-2 opens new era in European communications

european space agency
agence spatiale européenne

no. 14
may 1978

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Ireland has signed the ESA Convention and will become a Member State upon its ratification. Austria, Canada and Norway have been granted Observer status.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems,

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

The Directorate of the Agency consists of the Director General; the Director of Planning and Future Programmes; the Director of Administration; the Director of Scientific and Meteorological Satellite Programmes; the Director of Communication Satellite Programmes; the Director of the Spacelab Programme; the Technical Inspector; the Director of ESTEC and the Director of ESOC.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany.

THE SPACE DOCUMENTATION SERVICE (ESRIN), Frascati, Italy.

Chairman of the Council: Dr. W. Finke (Germany).

Director General: Mr. R. Gibson.

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée – l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) – dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, la Belgique, le Danemark, l'Espagne, la France, l'Italie, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. L'Irlande a signé la Convention de l'ESA et deviendra Etat membre de l'Agence lorsque la Convention aura été ratifiée. L'Autriche, le Canada et la Norvège bénéficient d'un statut d'observateur.

Selon les termes de la Convention: L'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

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Le Directoire de l'Agence est composé du Directeur général, du Directeur des Programmes futurs et des Plans, du Directeur de l'Administration, du Directeur des Programmes de satellites scientifiques et météorologique, du Directeur des Programmes de satellites de communications, du Directeur du Programme Spacelab, de l'Inspecteur technique, du Directeur de l'ESTEC et du Directeur de l'ESOC.

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LE SERVICE DE DOCUMENTATION SPATIALE (ESRIN), Frascati, Italie.

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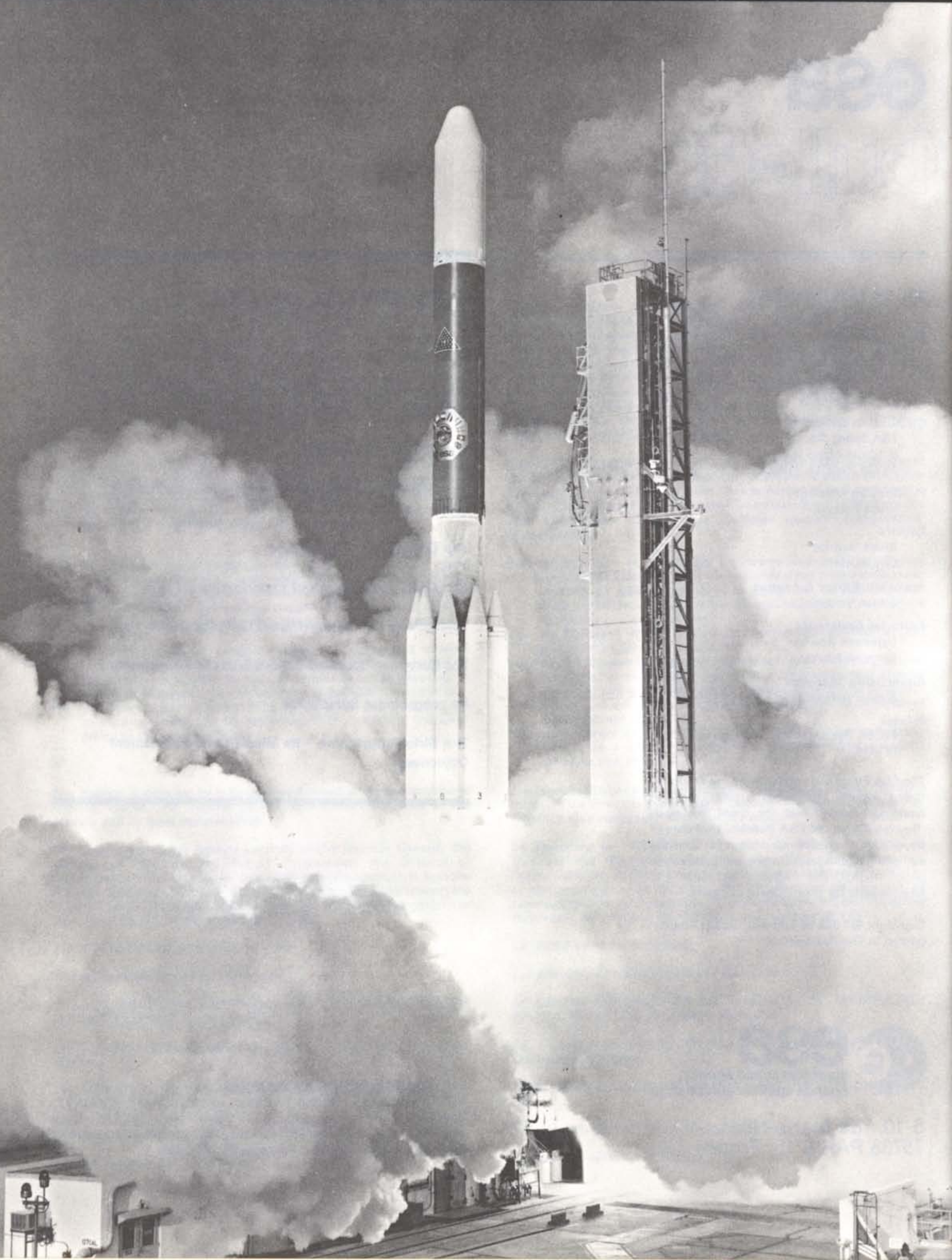


Introduction

Some two years ago, it was my privilege to introduce an issue of the ESA Bulletin (No. 5) which was devoted to the Agency's communications satellite programmes – for fixed services (telephony, television, data transmission, etc.), for mobile services (maritime and aeronautical purposes) and for broadcasting. With the successful launch of Orbital Test Satellite-2 (OTS-2), ESA's first communications satellite in-orbit – intended as a precursor of operational satellites for European regional fixed services in the 1980s – we again have an ESA Bulletin which concentrates on communications satellites and particularly on the Agency's programmes in the area of fixed services, i.e. point-to-point communications between fixed stations.

Launched from Cape Canaveral on 11 May at 22.59 GMT, by a Thor-Delta 3914 vehicle, OTS-2 replaces its twin which was destroyed last September when its US launcher exploded shortly after lift-off. The satellite has been designed to requirements defined in close consultation with European PTT and broadcasting authorities and for a minimum lifetime of three years. It is intended to pave the way for the operational European Communications Satellite (ECS) system. Four operational geostationary ECS satellites are planned to be launched in the 1980s, using Europe's Ariane launcher; development of the first two was approved by the Agency in March this year.

The purposes of OTS-2 are:
- to demonstrate the in-orbit performance and reliability of all on-board equipment;
- to carry out tests and experiments on radio-wave transmission through the atmosphere, on frequency re-use, and so on; and
- to provide a pre-operational-stage capacity for European telecommunications traffic.

ESA and Interim EUTELSAT (an organisation set up by the European Conference of PTT Administrations) are jointly responsible for the Orbital Test Programme to be undertaken with OTS-2 in conjunction with the national PTTs and other potential users. The Programme will involve not only large earth stations intended to be installed in France, Germany, Italy, Spain and the United Kingdom, but also smaller and cheaper terminals of a more domestic nature.

Il y a deux ans environ, j'ai eu le privilège de présenter un numéro spécial du Bulletin de l'ESA (No 5) qui était consacré aux programmes entrepris par l'Agence dans le domaine des satellites de communications pour le Service fixe (téléphonie, télévision, transmission de données, etc.), le Service mobile (communications maritimes et aéronautiques) et la radiodiffusion. Le lancement réussi du Satellite d'essais orbitaux no. 2 (OTS-2) – qui se trouve être le premier satellite ESA de communications à graviter en orbite et qui doit être le précurseur d'une série de satellites opérationnels pour le Service fixe régional européen dans les années 1980 – nous amène à présenter un nouveau numéro spécial du bulletin ESA traitant des satellites de communications et plus particulièrement des programmes de l'Agence dans le domaine du Service fixe, c'est-à-dire des communications point-à-point entre stations fixes.

Lancé de Cap Canaveral le 11 mai à 22.59 GMT, par une fusée Thor-Delta 3914, OTS-2 remplace son jumeau qui a été détruit en septembre dernier par l'explosion de son lanceur américain peu après le décollage. Fondé sur les besoins définis en étroite consultation avec les Administrations européennes des P&T et les organismes de radiodiffusion, le satellite a été conçu pour une durée de vie minimale de trois ans en vue de préparer un système opérationnel de Satellites européens de communications (ECS). Dans le cadre de ce système, il est prévu de lancer dans les années 1980 quatre satellites opérationnels ECS à mettre en orbite géostationnaire au moyen du lanceur européen Ariane; le développement des deux premiers satellites de la série a été approuvé par l'Agence en mars de cette année.

Le satellite OTS-2 a pour but:
- *de démontrer le bon fonctionnement et la fiabilité en orbite de tous les équipements embarqués;*
- *d'effectuer des expériences sur la transmission des ondes radio à travers l'atmosphère, la réutilisation des fréquences, etc;*
- *de fournir une capacité de trafic adéquate pour des transmissions européennes préopérationnelles.*

L'ESA et EUTELSAT intérimaire (organisation créée par la Conférence européenne des Administrations des P&T) sont conjointement responsables de l'exécution du programme d'essais orbitaux avec OTS-2, qui doit être

W. Luksch

After recounting the philosophy underlying ESA's development of OTS and the technology involved, this Bulletin goes on the describe the ESA/CEPT test programmes in some detail as a backdrop to the subsequent descriptions of the future operational ECS system.

The successful launch of OTS-2 is a major step by Europe in demonstrating its ability to provide the technology for space communications. It is hoped that this will foster the acceptance of European expertise as a major force in the World's growing communications markets and lead eventually to European industry providing communications satellites for countries outside Europe – thus reaping industrial benefit from the investments made by European governments in communications satellite technology for OTS and its successors. □

conduit de concert avec les Administrations nationales des P&T et d'autres utilisateurs potentiels. Ce programme mettra en jeu non seulement de grandes stations terriennes, à installer en Allemagne, en Espagne, en France, en Italie et au Royaume-Uni, mais également des terminaux plus petits et moins chers à vocation plus locale.

Après avoir rappelé les principes sur lesquels a été fondé le développement de l'OTS par l'ESA, ainsi que la technologie en cause, le présent bulletin expose de façon assez détaillée les programmes d'essais ESA/CEPT avant d'aborder la description du futur système ECS opérationnel.

Le lancement réussi d'OTS-2 marque une étape décisive pour l'Europe car il démontre sa maîtrise de la technologie des communications spatiales. Il est permis d'espérer que cette démonstration de ses compétences contribuera à lui assurer une place de premier plan sur le marché mondial prometteur des télécommunications et ouvrira à son industrie des débouchés hors d'Europe pour la fourniture de satellites de communications. Les Européens pourront ainsi récolter sur le plan industriel les fruits des investissements que leurs gouvernements ont consentis dans le domaine de la technologie des satellites de communications pour réaliser OTS et ses successeurs. □

W. Luksch,

Director of Communications Satellite Programmes, ESA

Why Europe must Invest in Communications Satellite Systems

E.S. Mallett, Chairman of ESA Joint Communications Board

The launch of the Orbital Test Satellite (OTS) is a step towards a goal of a European regional communications satellite system based on the ECS satellite. Although this is a valuable achievement in itself, the ultimate goal is a share of the World market in regional satellite systems. Although it can be said now that European firms have a high technical competence in the telecommunications satellite field, they have yet to show their commercial capability. ESA must continue to maintain a level of investment which will enable member countries to achieve this aim, one that is unlikely to be won by any member country on its own.

TECHNOLOGY ASPECTS

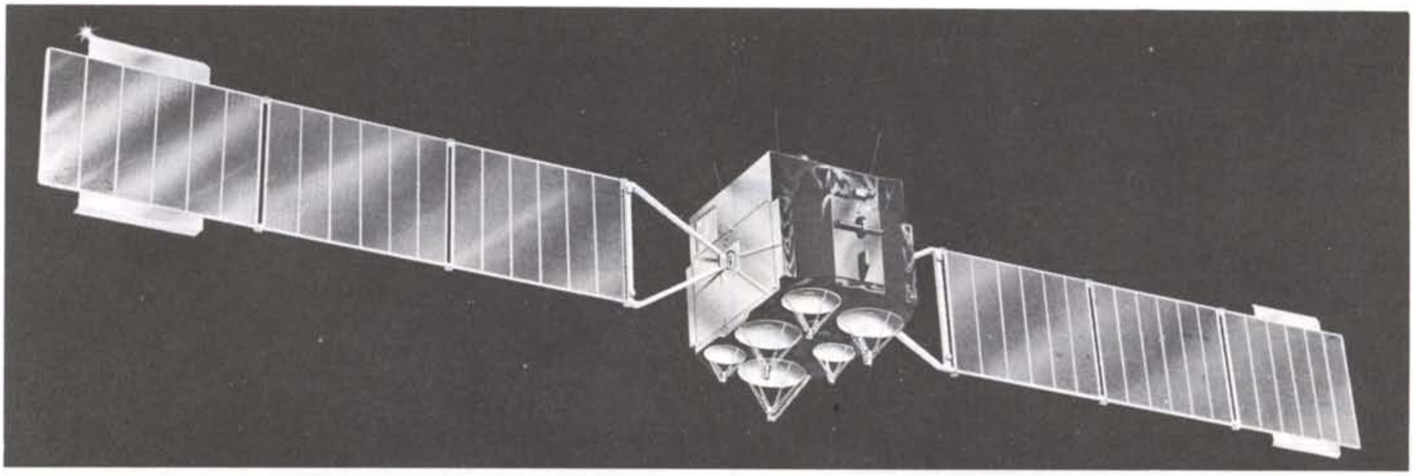
The present high technology of communications satellites is demonstrated by the latest Intelsat series. The trend is towards higher frequencies, higher powers and larger satellites. The 4 to 6 GHz bands are becoming crowded, and so the 11 to 14 GHz bands are being used by Europe and Japan, as well as by the newest of the Intelsat series. Maximum use should be made of the 4 to 6 GHz band, due to greater atmospheric attenuation of 11 to 14 GHz frequencies; nevertheless, the latter band has great potential, as indeed has the 20 to 30 GHz band. The trend towards the higher frequencies will develop as traffic increases.

IMPORTANCE OF THE GROUND SEGMENT

The higher radiated transmitter powers from satellites will enable cheaper and simpler earth stations to be used, an economic benefit for the overall system because the investment in earth stations, particularly in direct television broadcasting from satellites, is greater than that in the satellites themselves. Another factor is that more money is to be made from earth stations. There is lively competition between firms, which must produce the right product at the right time and at the right price – something that could well be said about any commercially successful product, I suppose. While on the subject of earth stations, I should mention the ESA studies which have shown the potential for communication with offshore oil production platforms using relatively cheap terminals.

CONCLUSIONS

There is a great potential for communications satellite systems in the World. European countries are unlikely to achieve commercial success alone, but together they can match the World, provided the investment continues. □



The Orbital Test Satellite

R. Collette, B. Stockwell & P. Bartholomé, Communications Satellites Department, ESA

The Orbital Test Satellite (OTS) is a three-axis stabilised geostationary satellite which has been developed to prepare for a European Communications Satellite (ECS) system projected for operational use in the 1980s. Built by Hawker Siddeley Dynamics, leading the MESH Consortium, under contract to ESA, OTS will be the third communications satellite to operate in the 11 and 14 GHz frequency bands*. Its prime purpose is to act as a test bed for the hardware, technologies and communications concepts that will be needed for ECS and to provide experience in the utilisation of an operational system. More specifically, the objectives pursued are:

a. to confirm the satellite's concept, its main characteristics being those of the future ECS satellites, and to check the operational reliability of the on-board equipment
b. to validate the new communications techniques proposed (re-use of the spectrum based on polarisation discrimination, digital transmission and speech interpolation, time-division multiple access)
c. to evaluate the effect of propagation phenomena in the atmosphere on the quality of transmission
d. to study the technical problems arising from the utilisation of the system on a pre-operational basis.

In addition, OTS will be used for a variety of experiments in connection with possible novel applications for communications satellites in Europe.

OVERALL DESCRIPTION

A modular approach has been adopted in designing the satellite, which consists of a service module, providing all the basic service functions, and a communications module, carrying the payload. This modular concept allows the spacecraft to be adapted easily and economically for different missions, the Marots maritime communications satellite being a good example in this respect. Moreover, the structure has been designed for a heavier overall mass than is constituted by OTS itself, and thus has significant growth potential for meeting future requirements, such as those of the operational ECS satellites.

The satellite's configuration is shown in Figure 1, and an impression of its modular construction can be obtained from Figure 2. The six-sided satellite weighs 865 kg at lift-off and 444 kg at beginning-of-life in geostationary orbit. It is 2.39 m high, 2.13 m long and spans 9.26 m with its solar arrays deployed.

TABLE 1
Summary of Mass Budget

Subsystem	Comm. module (kg)	Service module (kg)	Total (kg)
Repeater	42.8	0	42.8
Antennas	14.4	0	14.4
TTC	8.4	14.8	23.2
Power	0	58.7	58.7
Solar array	0	29.3	29.3
BAPTA	0	8.3	8.3
Electrical distr. services	6.4	14.1	20.5
AOCS	5.0	33.9	38.9
RCS	0	25.8	25.8
Structure	19.7	43.1	62.8
Thermal	8.3	13.7	22.0
Instrumentation	0.9	1.3	2.2
Pyrotechnics	0.2	2.1	2.3
Radiation shielding	3.4	6.2	9.6
Subsystem totals	109.5	251.3	360.8
Balance mass			4.5
Fuel (hydrazine)			68.1
Apogee motor (incl. fuel)			432.1
Adaptor			36.3
Total mass at transfer-orbit injection			901.8

* The first two were the Canadian CTS satellite, and Sirio.

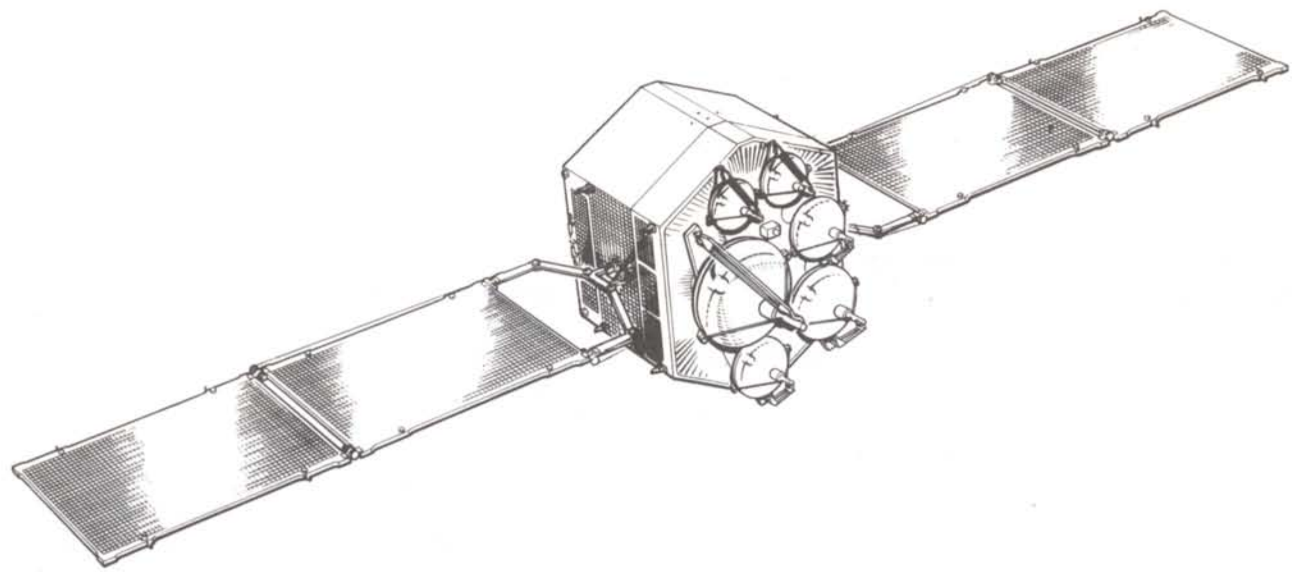


Figure 1 – OTS in orbital configuration.

The service-module structure, which weighs 43 kg, is built around a central conical tube that provides both the mounting for the Apogee Boost Motor (ABM) needed to propel the satellite from transfer to geostationary orbit, and the interface with the Delta 3914 launch-vehicle adaptor. The service module carries the propellant tanks, the momentum wheels, the gyroscopes and the bulk of the electronic units. On the long sides of the spacecraft, honeycomb sandwich panels carry various pieces of equipment, and in particular the Bearing and Power-Transfer Assemblies (BAPTAs) that provide the interfaces with the two solar arrays, each of which consists of two hinged panels. During launch and transfer orbit, the arrays are folded against the satellite north and south faces, so that half of their surface is exposed to provide power during this phase of the mission. In normal operation, they are fully deployed and steered independently to track the Sun, each making one complete revolution per day with respect to the satellite body.

The communications-module structure weighs 20 kg. The main tray contains the repeater package and, mounted on a separate panel, the earth-pointing equipment in the form of the six SHF antennas and the earth sensors.

The overall mass characteristics of OTS are summarised in Table 1.

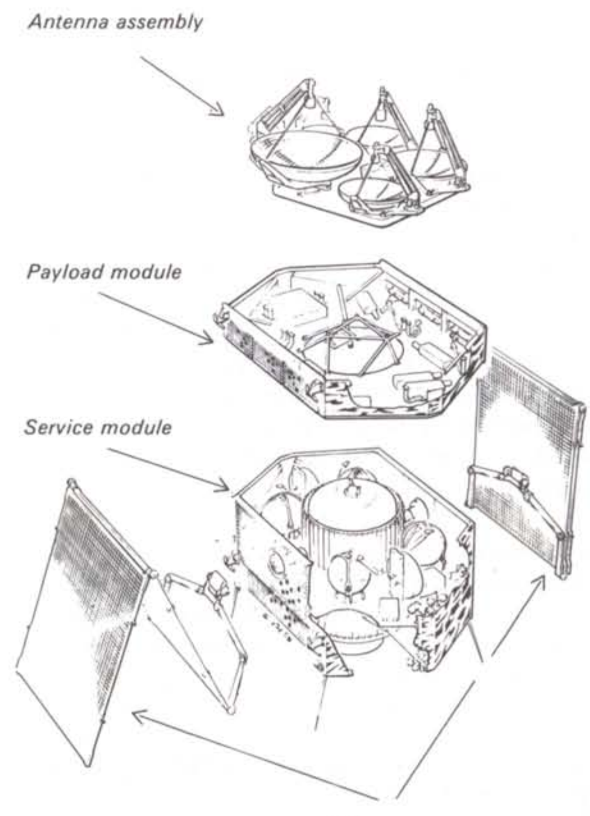


Figure 2 – Exploded view of the satellite.

THE ATTITUDE AND ORBIT CONTROL SUBSYSTEM (AOCS)

The AOCS consists of the various attitude sensors, measurement and signal-processing electronics, and actuators needed for attitude measurement, attitude control, and orbit control during transfer orbit, drift to station, and on-station operation.

During transfer orbit, when the satellite is spin-stabilised, the AOCS uses a V-beam sun sensor, a dual-beam infrared pencil beam earth sensor, a passive nutation damper, control electronics, and hydrazine thrusters to provide attitude sensing and attitude determination and correction (with the aid of ground-station control). Following Apogee Motor Firing (AMF) in order to acquire the operational three-axis-controlled attitude, additional sun sensors are used, together with a Reaction Control System (RCS). Station acquisition manoeuvres are performed using the RCS, under the control of the attitude control system.

In OTS's normal, on-station, earth-pointing operational mode, the AOCS uses a fixed momentum wheel in conjunction with the RCS as the primary control actuator and a two-axis earth sensor for the attitude reference in pitch and roll. The momentum wheel absorbs pitch disturbances by varying its speed. When the wheel speed reaches the limit of its normal operating range, the thrusters are used to off-load momentum and return the wheel speed to nominal. On-station orbit control is performed using the RCS, in conjunction with a rate-integrating gyro, for yaw attitude-error control.

The performance of the AOCS is such that, when all sources of error are included, the electrical bore sight of the antennas is maintained to within a half- cone angle of 0.2° (3σ) and the satellite yaw error to within $\pm 0.5°$ (3σ) under all orbital conditions.

THE TELEMETRY, TRACKING AND COMMAND SUBSYSTEM (TTC)

The TTC subsystem performs the following functions:

a. collection, serialisation, and transmission of all telemetry data to Earth
b. reception and retransmission of ranging signals required for the determination of the satellite's orbital position
c. reception and distribution of all spacecraft commands.

Prior to normal on-station operation, and also as a back-up mode, the subsystem operates at VHF on 137.05 MHz for telemetry and 149.34 MHz for command. In normal mode, it operates at SHF, 14.125 GHz for command and 11.575 GHz for telemetry, within the communications payload frequency bands. To maintain the basic satellite modular concept, the TTC subsystem is divided into a service module and a communications module. The service module consists of a VHF antenna and branching unit, a VHF transponder, a priority select and interface unit, and a decoder and encoder. The communications module consists of a pair of redundant UHF receivers, which are fed by signals extracted from the repeater subsystem following down-conversion, a pair of redundant SHF transmitters, which feed the TM signals via diplexers into the Eurobeam transmit antennas, and the decoder and encoder.

During all mission phases, a telemetry bit rate of 160 bit/s is used, with PCM/PSK phase modulation. Each complete format lasts 25.6 s and contains 300 analogue channels, 50 serial digital channels, and 160 bi-level channels. The telecommand capacity provides for 383 on-off commands and 32 memory load commands using PCM/PSK amplitude modulation; the telecommand bit rate is 750 bit/s.

Because of the test-programme requirements, OTS carries significantly more instrumentation, mainly in the form of temperature monitors, than an operational satellite.

THE POWER SUBSYSTEM

Power for the satellite is provided in sunlight by solar arrays, and in eclipse by batteries. During the spin-stabilised transfer phase of the mission, the service module power requirements of 80 W are met by the power generated by the outer panels of the folded solar array. On-station power is provided by the two deployed solar arrays, which are continuously aligned with the Sun.

TABLE 2
Summary of Power Budget

Subsystem or part of subsystem	Eleventh/Twelfth Transfer Orbit			On-station (at 3 years)		
	Launch (W)	Sunlight (W)	Eclipse (W)	Solstice (W)	Equinox Sunlight (W)	Equinox Eclipse (W)
Repeater	0	0	0	354.0*	345.0*	164.5°
TTC	46.5	46.5	46.5	41.5	41.5	41.5
AOCS	1.0	7.5	7.5	34.0	34.0	34.0
BAPTA	0	0	0	3.0	3.0	2.5
Thermal	0	0	0	61.0	77.5	0
Instrumentation	2.0	2.0	2.0	2.0	2.0	2.0
Pyrotechnics	0.5	0	0	0	0	0
Power	26.0	25.5	26.0	26.0	26.0	26.5
Subtotal	76.0	81.5	82.0	521.5	529.0	271.0
Battery recharge		58.0		9.0	56.0	
Array capability		181.0		555	594	

* For five-channel operation in sunlight and two-channel operation in eclipse.
° For longest eclipse (72 min).

Power will be available to operate six repeater channels for three years, and five channels to the end of five years.

Power and signal transfer from the solar array to the spacecraft is achieved via a slip-ring assembly. A digital shunt regulator system, controlling seven switchable solar-array sections, together with a proportional shunt section, regulates the main power-bus voltage of 50 V DC ±1%. Separate regulators are used for the AOCS, TTC and instrumentation subsystems, and to control power to the repeater subsystem of the communications payload. The Electronic Power Conditioners (EPCs) of the Travelling-Wave-Tube Amplifiers (TWTAs) are supplied directly from the 50 V main bus.

During eclipse, power is provided from a nickel-cadmium battery by a Pulse-Width-Modulation (PWM) boost regulator that then controls the main-bus voltage. The battery package is designed to provide up to 290 W at end-of-life through a 72 min eclipse, at a maximum depth of discharge of 70%. This battery energy is more than sufficient to allow operation of two repeater channels through each eclipse, in addition to providing power for all necessary housekeeping functions. The battery is charged via redundant series chargers; battery charge and discharge control is provided by an ampere-hour meter and battery-cell monitoring.

The power characteristics of OTS are summarised in Table 2.

OTHER SERVICE SUBSYSTEMS

THERMAL CONTROL

The function of the thermal control subsystem is to provide a satisfactory thermal environment for all on-board equipment during all mission phases. It employs aluminium radiator plates for thermal control of the TWTs and an appropriate combination of thermal finishes, coatings and super-insulation for overall satellite thermal regulation. Heaters are provided where necessary to maintain the requisite thermal conditions during those phases of the mission when passive means alone are insufficient.

APOGEE BOOST MOTOR

A solid-propellant apogee boost motor is used to impart sufficient velocity increment to the satellite at apogee of the transfer orbit to inject it into a near-synchronous circular orbit with approximately zero inclination. Subsequent fine corrections to acquire operational orbit and station are provided by the hydrazine system. An Aerojet SVM-7 motor is used on OTS.

INSTRUMENTATION

The instrumentation subsystem comprises all sensors and associated conditioning circuitry incorporated into the satellite both for housekeeping and for carrying out in-orbit performance evaluations. These sensors are additional to those already incorporated in various items of equipment to monitor their particular performances.

PYROTECHNICS

The pyrotechnic subsystem consists of all the components required to process command signals and power supplies for the activation of pyrotechnically initiated devices used for:

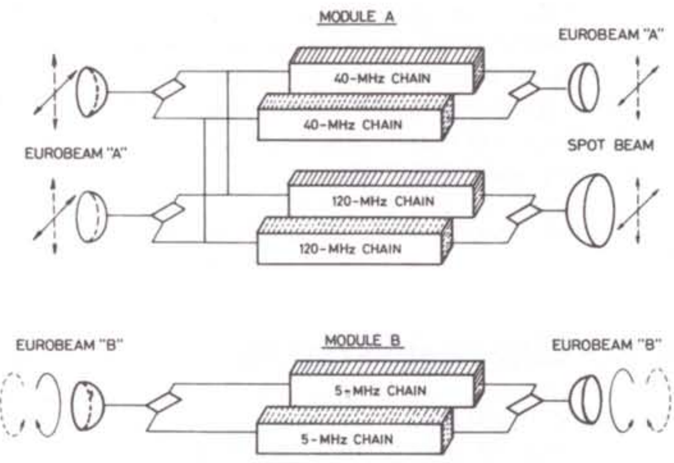


Figure 3 – Communications payload of OTS.

- ABM ignition
- release of stowed solar-array panels
- unlocking of antenna-pointing mechanism and, if necessary, release for failsafe zero return
- release of BAPTA launch-phase lock.

THE COMMUNICATIONS PAYLOAD

The communications payload provides for the reception of signals at 14 GHz, their frequency translation, and retransmission at 11 GHz after amplification. To meet the various mission requirements of OTS, the communications payload has been split into two parts, called Modules A and B. The block diagram of Figure 3 illustrates their composition.

Module A is a reduced version of the payload that could be carried by operational satellites. It comprises four repeater chains, two of 40 MHz nominal bandwidth, and two of 120 MHz. Each pair is arranged in frequency re-use configuration, with the two chains operating in the same frequency channel. Separation between signals on the upward and downward paths is provided by orthogonal linear polarisations. Module A will provide for retransmission of signals such as telephony in PSK/TDMA and television between earth stations having overall characteristics similar to those of the projected operational system. The UHF telecommand receivers and SHF telemetry transmitters also form part of Module A.

The receive antenna system consists of two identical redundant dishes, giving full European coverage with a nominal half-power beam width of 7.5° × 4.25° (Eurobeam 'A' in Fig. 4). Similarly, the transmit antenna associated with the 40 MHz chains produces an elliptical beam for European coverage. The transmit antenna used for the two 120 MHz chains is a Spotbeam type with nominal circular half-power beam width of 2.5°.

The other module, Module B, is intended for propagation experiments and narrow-band transmission tests. It comprises two repeater chains of 5 MHz nominal bandwidth, each with an associated on-board beacon signal generator and arranged in a frequency re-use configuration employing orthogonal circular polarisations. One repeater chain acts as a standby for the other, but both chains may be run simultaneously for frequency re-use experiments if required. The two chains have substantially higher gain than those of Module A and can therefore be accessed by small and relatively inexpensive earth stations. Separate dual circular polarisation antennas with a nominal elliptical beam width of 5° × 3.5° (Eurobeam 'B' in Fig. 4) are used for reception and retransmission.

Module A can be subdivided into three sections: a broad-band receiving section, a channelised section, and an output section. The broad-band section consists of four parallel channels (two redundant pairs) which are fed by the respective outputs of the antenna subsystem. Waveguide filters, parametric amplifiers, down-converters, and branching networks form the essential parts of this section. The two branching networks provide for the distribution of the communications signals to the input of the channelised sections and the output to the UHF telecommand receivers.

The channelised section consists of two 40 MHz and two 120 MHz chains at intermediate frequency (800-1300 MHz). After selection in 40 and 120 MHz filters, the signals are amplified in main IF amplifiers which allow signal level control on command. Linear up-converters perform frequency translation to the transmit frequencies.

In the subsequent output sections, the communications signals are amplified in multicollector TWTAs to the

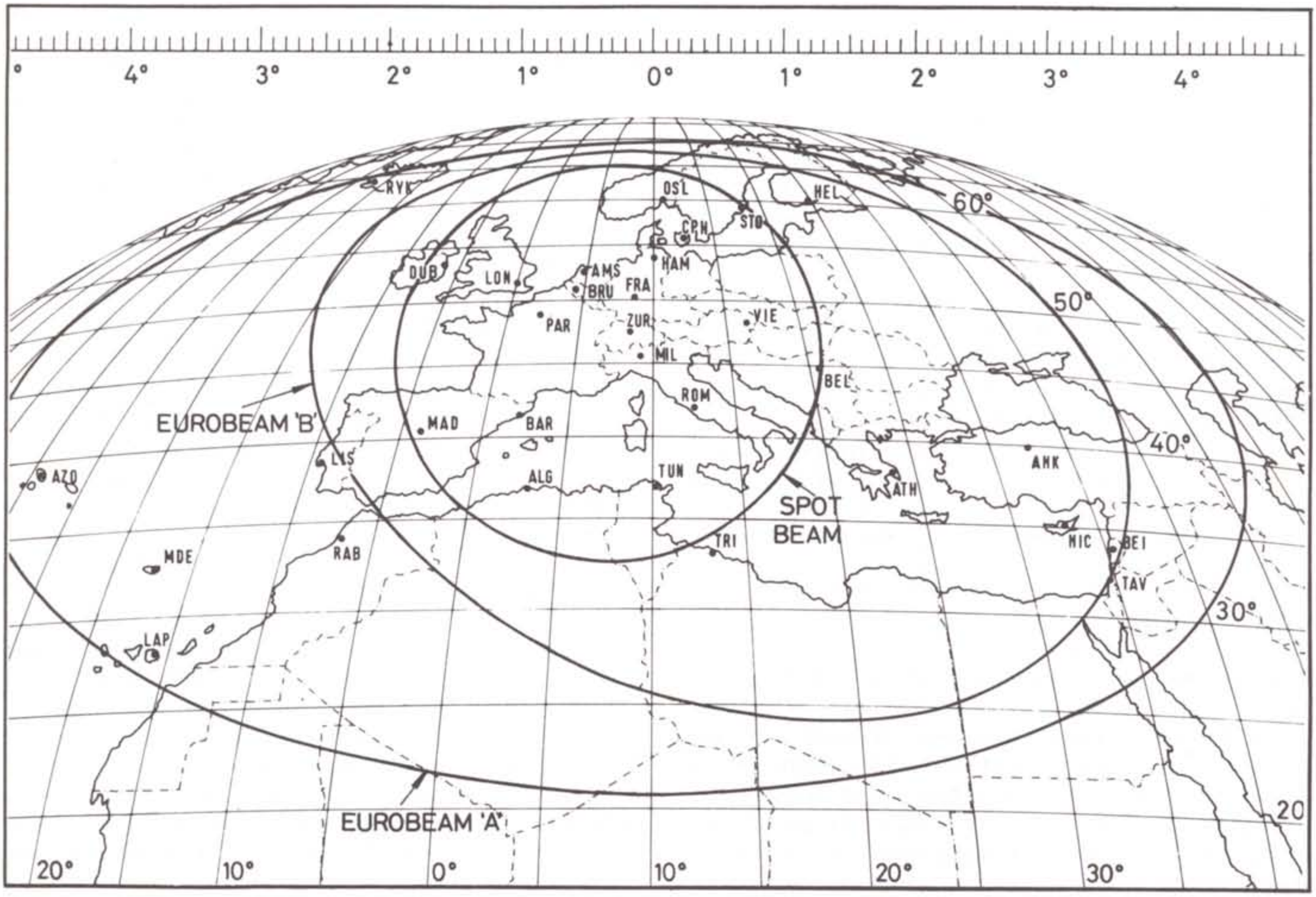


Figure 4 – Coverage zones of the OTS antennas.

nominal 20 W output level and passed through the output network to the antenna subsystem. The output network of the 40 MHz chains is designed as a diplexer to combine the RF signals from the SHF telemetry transmitter with the communications signal. Redundant TWTAs are provided, one for each pair of chains, and changeover at input and output is accomplished by RF circulator switches.

Module B consists of two redundant narrow-band chains, similar in basic design to Module A, except for the up-converters which have a limiting characteristic. Module B incorporates a beacon generator which provides unmodulated signals for downlink propagation measurements. The beacon signal is combined with the RF signal in front of the TWT in both chains via an RF hybrid.

The necessary oscillator frequencies for Modules A and B are delivered by the carrier supply unit, which provides six outputs for up- and down-conversion. A separate power-supply unit performs the necessary allocation and distribution of DC lines excluding the TWTAs, each of which incorporates its own electronic power conditioner. Table 3 lists some of the main payload characteristics.

TABLE 3

Overall Characteristics of Communications Payload (Beginning of Life)

Repeater Chains							
Module designation	A				B		
Chain designation	2	$\overline{2}$	4	$\overline{4}$	RL	LR	
Centre frequency							
– Receive	14172.5	14172.5	14302.5	14302.5	14457.5	14457.5	MHz
– Transmit	11510.0	11510.0	11640.0	11640.0	11795.0	11795.0	MHz
Nominal channel bandwidth	40	40	120	120	5	5	MHz
Overall noise figure	5.0	5.0	5.0	5.0	5.0	5.0	dB
Max. output level	11.5	11.6	12.4	11.8	12.3	11.9	dBW
Input level for max. output							
– Max. gain setting	−101.5	−101.5	−101.5	−101.5	−123.0	−125.0	dBW
– Min. gain setting	−87.5	−87.5	−87.5	−87.5	−93.0	−95.0	dBW
Antenna beam-Polarisation							
– Receive	Euro 'A' – X	Euro 'A' – Y	Euro 'A' – X	Euro 'A' – Y	Euro 'B' – R	Euro 'B' – L	
– Transmit	Euro 'A' – Y	Euro 'A' – X	Spot – Y	Spot – X	Euro 'B' – L	Euro 'B' – R	
Maximum EIRP at beam centre	38.0	38.4	47.9	47.3	41.4	41.0	dBW
Maximum G/T at beam centre	−3.0	−3.0	−3.0	−3.0	−0.4	−0.4	$dB(K^{-1})$
Beacons							
Beacon designation	TM	$\overline{TM}$			B_0	B_1	
Frequency	11575.0	11575.0			11786.0	11786.0	MHz
Output level	−7.0	−7.0			1.6	1.3	dBW
Antenna beam-Polarisation	Euro 'A' – X	Euro 'A' – Y			Euro 'B' – R	Euro 'B' – L	
EIRP at beam centre	19.5	19.5			31.2	31.1	dBW

CONCLUSION

Coming after eleven scientific satellites and Meteosat, OTS is intended to pursue the era of applications satellites for ESA. This will no doubt mean a break with old traditions and the adoption of new working habits in the Agency. Unlike most of its predecessors, which were linked to the European Space Operations Centre (ESOC) by an 'umbilical cord' and transmitted all the information they gathered through this exclusive channel, OTS will be accessed directly by a vast number of experimenters who will collect their data themselves using their own earth stations and equipment. Today more than 35 such stations are already complete or under construction. ESA itself has set up seven, the largest of which, owned jointly with Telespazio and installed at Fucino in Italy, will be used both for controlling the satellite and for communications tests and experiments*. Being the satellite operator and an experimenter, the Agency will be faced with the challenging task of co-ordinating its own activities in real time with those of a large community of experimenters scattered throughout Europe and, before long, in North Africa and the near-East.

* See the article on 'The Orbital Test Programme', elsewhere in this Bulletin.

Also, with OTS the Agency has embarked on an open-ended programme, in the sense that this satellite will be followed by a first generation of ECS satellites to be launched from 1981 onwards, and these in turn will have to be replaced probably before the 1980-90 decade is over. Communications, once established, must be maintained and improved and experience with INTELSAT has shown that communications satellites breed very rapidly. This will involve ESA in many long-term commitments and obligations, all of which cannot be clearly foreseen at the present time.

ACKNOWLEDGEMENT

The satellite described in this article is the fruit of several years of effort by a large team of people within ESA and the MESH Consortium, too numerous to be mentioned here by name. Some have had to leave before seeing the results of their work and others have joined after the project had started. The authors have had the privilege of being among those who saw the bird born after a long and painful gestation, and also now have the pleasure of seeing it fly. They would like to extend their thanks to their colleagues and to all those, both inside and outside ESA, who have contributed to the success of the project. □

The OTS Development/Test Programme — Contractor Summary

C. Wearmouth, Hawker Siddeley Dynamics Ltd., Stevenage, UK

The industrial contract for the development of OTS was awarded to the MESH Consortium, led by Hawker Siddeley Dynamics, in November 1973. As the first communications satellite procured by the European Space Agency, OTS has proved to be one of the most advanced and hence demanding programmes so far undertaken in Europe. In addition to the demanding goals in terms of technical performance associated with the satellite's role as a technology test bed for the future European satellite communications system, the contractors have been obliged to respect equally demanding goals in terms of schedule and financial constraints.

INDUSTRIAL ORGANISATION

The industrial team engaged on the OTS programme has consisted essentially of the MESH Consortium, led by HSD, joined by two further companies, namely AEG-Telefunken and Selenia. As Prime Contractor, HSD has been responsible for the contract with the customer, ESA, and hence for overall project management and system engineering. HSD itself placed contracts with six main co-contractors, (MATRA, ERNO, SAAB, HSD itself, AEG-Telefunken and Selenia) at subsystem level, and these companies in turn placed subcontracts with some 40 other companies, including the remaining MESH partners Aeritalia, Fokker-VFW and INTA (see Table 1).

The MESH companies are therefore basically responsible for the subsystems of the bus, that is the service functions of the satellite, while AEG-Telefunken and Selenia are responsible for the payload subsystems – the communications repeater and antenna assembly, respectively.

All the contracts are of the fixed-price type, with the exception of the HSD Prime Contractor management tasks and the integration of the complete satellite which was carried out by MATRA in France. These latter two activities are undertaken on a cost-reimbursement basis. This means that about 80% of the overall project is 'fixed-price', and even the cost-reimbursement activities are subject to penalties or incentives on the basis of actual expenditure compared with target cost.

Almost all of the European companies involved in the programme, representing aerospace industries in ten European countries, share in a common incentive/penalty scheme based on timely delivery of the spacecraft and on its satisfactory orbital performance over a five-year period.

Some aspects of the contractual arrangements have been rather novel. Satellite integration, for example, which is classically one of the tasks of the Prime Contractor, was subcontracted in the case of OTS. To help make such an approach work effectively, HSD and MATRA entered into a special profit/loss agreement, both recognising at the outset the risks associated with moving responsibility for satellite integration from the Prime Contractor. In the event, the arrangement has proved completely successful.

Another aspect of the project's management which merits mention is the exchange of personnel between companies engaged on the project – for example, between HSD and MATRA in their respective roles, and AEG-Telefunken personnel seconded to the prime and integration contractor teams. Moreover, almost all of the MESH companies seconded staff to the integration team for various periods. In addition, HSD has had resident product-assurance personnel attached to the integration team throughout the programme.

DEVELOPMENT PROGRAMME

At the start of the project, the development plan for OTS involved the following satellite-model philosophy:
- structural model
- thermal model
- engineering model (refurbished thermal model)
- qualification model
- flight model.

The initial satellite design was based on the use of a Delta-2914 launch vehicle. In July 1974, it was decided to use an uprated Delta 3914 vehicle, giving an increase in useful payload of some 200 kg. In conjunction with this change of launcher it was decided to take the opportunity

TABLE 1

Major Programme Co-contractors, and Subcontractors

MATRA (F)	Assembly, integration and testing, Electrical Ground-Support Equipment (EGSE), Attitude and Orbit Control Subsystem
Aeritalia (I)	EGSE equipment integration support
Fokker (NL)	Nutation damper
Galileo (I)	Infrared earth sensors
Sodern (F)	Infrared earth sensors
HSA (NL)	Momentum wheel
Teldix (D)	Momentum wheel
TNO (NL)	Sun sensors
CIR (CH)	EGSE equipment
Honeywell (US)	Gyros
ERNO (D)	Structure, Thermal, Reaction Control System (RCS)
Aeritalia (I)	Structure manufacture
PSI (US)	RCS tanks
Carleton (US)	RCS valves
Statham (US)	Pressure transducer
SAAB-SCANIA (S)	Telemetry, tracking and command
BTM (B)	UHF receiver, VHF transponder
LCT (F)	VHF transponder, SHF transmitter
Christian Rovsing (D)	Priority Select and Interface Unit (PSIU)
HSD (UK)	Power, electrical distribution, Bearing and Power Transfer Assemblies (BAPTAs), Mechanical Ground-Support Equipment (MGSE)
TRW (US)	Electronic parts, Consultancy
Aerojet (US)	Apogee motor
MBB (D)	Solar array
BTM (B)	Squib driver unit, TTC converter, Instrumentation electronic units
HSA (NL)	Battery monitoring and control unit, Battery and protective unit
Contraves (CH)	MGSE
INTA (E)	MGSE, VHF antennas
AEG-TELEFUNKEN (D)	Repeater (incl. some equipment and overall integration)
Thomson-CSF (F)	Travelling Wave Tubes (TWT), Broadband receiver, Output network
GTE (I)	Paramplifier
FIAR (I)	RF hybrid, Carrier supply, TWT power unit
Selenia (I)	Up-converters, RF switch
MSDS (GB)	IF filters
L.M. Ericsson (S)	Input filter, Beacon generator
ETCA (B)	Power supply
Radial (F)	Attenuators
SELENIA (I)	SHF antennas
DBA (US)	Test support
Fenwick (F)	Flexible waveguide

of introducing some useful satellite design improvements. In deriving the development plan for the revised programme, it was essential to make maximum use of hardware already well advanced in construction in order to minimise both the financial and schedule impacts. The model philosophy was adapted as follows: (i) thermal model (2914 standard) refurbished to preliminary structural testing; (ii) engineering model (3914 standard) using 2914 structural model; (iii) structural model (3914 standard); (iv) qualification model (3914 standard), and (v) flight model (3914 standard). The revised programme is shown in Figure 1.

- *Repeater*
  - addition of a redundant TWTA in one 40 MHz chain and in one 120 MHz chain
  - addition of one complete beacon channel with parallel-operation capability

- *RCA*
  - larger hydrazine tankage capacity

- *Solar array*
  - extended solar-array yoke for OTS/Marots compatibility

- *ABM*
  - replacement of SVM6 motor by an SVM7.

These preliminary modifications themselves gave rise to a number of further modifications:
- height increase in service-module structure
- modified equipment layout
- modified thermal control
- increase in power, particularly during eclipse
- harness changes.

An important feature of the OTS development programme has therefore been the existence of two design standards, designated 2914 and 3914, representing the status before and after launch-vehicle conversion.

The design/development strategy adopted was:
- to test to the original standard to corroborate theoretical predictions
- to extrapolate theoretically to the revised standard, having confirmed the accuracy and having established confidence in the theory

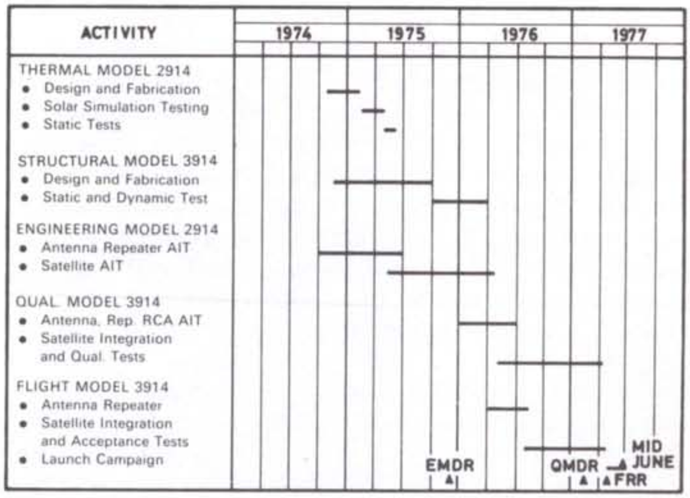


Figure 1 – OTS programme plan.

- to confirm by testing at the revised standard.

In all cases, the final confirmation was provided by the qualification model. Although sufficient confidence existed in the thermal analysis to rely on testing at the 2914 standard and thence with the qualification model, this was not the case for the structural design. Consequently, a definitive 3914-standard satellite structure was included for formal structural qualification.

THERMAL TEST PROGRAMME

The solar-simulation and thermal-balance testing on the thermal model was performed during March and April 1975 at the SOPEMEA (Toulouse) facility, and the results were used to confirm and update the spacecraft mathematical models (2914-standard). With this experience, it was possible to develop a set of 2914-standard mathematical models that showed a satisfactory temperature environment for the majority of the spacecraft equipment. Some minor problems were identified, and simple modifications were introduced to rectify them.

STRUCTURAL TEST PROGRAMME

The programme initially comprised two stages. Acoustic-noise and sinusoidal testing, including the simulation of static conditions, were performed at Industrieanlagen-Betriebsgesellschaft (IABG), Munich, using the refurbished 2914 thermal model, and good correlation between analysis and test results was obtained. Subsequently, a full programme of static-loading, sinusoidal, acoustic noise, and separation shock testing was completed on a definitive 3914 structural model. Results from the 2914 tests compared well with analysis predictions, and on this basis fabrication of the flight-structures was authorised.

For the 3914 model, test levels were increased as a result of a coupled analysis with the launch vehicle, and a local retest was necessary to resolve a failure in the floor core material at the tank/strut interface during static testing. With this single exception, adequate margins were established for all structural components. The resonant frequencies of the structure on test again compared well with calculations. Significant cross-coupling between axes was observed, as predicted by analysis. The test levels were notched to prevent overtesting at the basic structural frequencies and at the array and antenna fundamental frequencies. Figure 2 shows the structural model (3914) in the Dynamic Test Chamber at ESTEC.

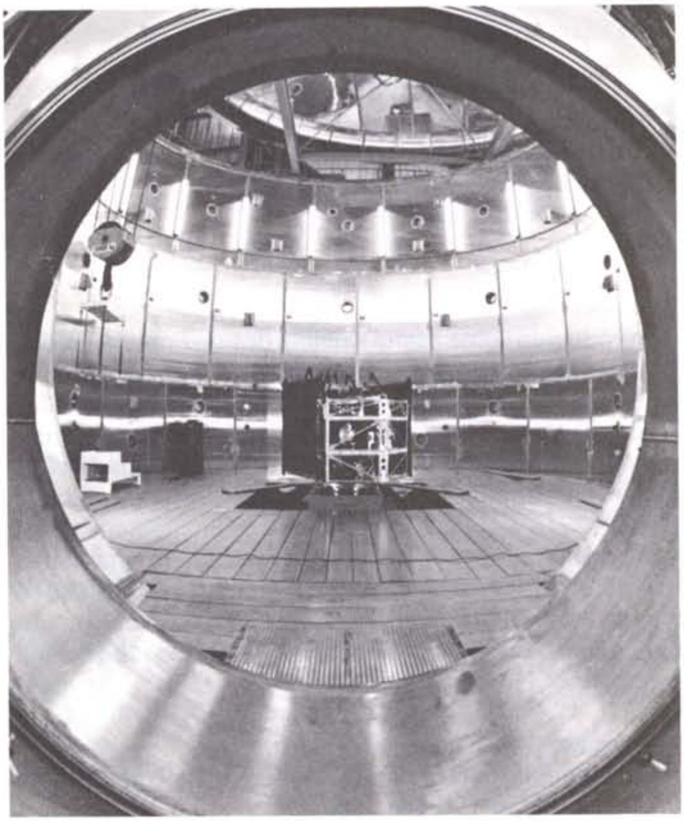


Figure 2 – OTS structural model under test at ESTEC.

ENGINEERING MODEL INTEGRATION AND TEST

Integration and testing of the engineering model were completed successfully at MATRA, Toulouse, at the beginning of 1976. A typical test configuration is shown in Figure 3. The objectives identified for this satellite-based part of the activity were: verification of mechanical interfaces between equipments and structure, verification of electrical interfaces between equipments, and verification of mutual compatibility of the constituent subsystems, both from the performance and interface points of view.

The integration and test programme was divided into the following important phases:

Subsystem integration: installation of equipment into the satellite

Subsystem compatibility: confirmation of correct interfaces between each subsystem and the satellite power supplies and TTC subsystem

System compatibility: coupling of the communication and service modules, and demonstration that system performances were unaffected, with all subsystems being exercised in the various modes of operation

Integrated Systems Test (IST): a classical run through the mission sequence to verify system integrity in a more formal manner than encompassed under system compatibility

Power stability and profiling

Electromagnetic cleanliness (EMC) testing

Special performance testing: tests whose nature is such that they cannot be carried out during IST; they require the use of hard-line connections at equipment level

RF indoor testing: radiation at 11 to 14 GHz inside an anechoic tunnel to provide a total end-to-end communications test.

Engineering-model testing was very satisfactory in that few significant design or interface problems were encountered. As a result of the engineering-model experience, minor changes were made in the positioning of some equipment items to ease the integration task for the qualification model. From the electrical point of view, some problems occurred with a few units during EMC testing, although overall the electromagnetic-cleanliness design requirements were shown to be satisfied with good margins. This was confirmed by an unscheduled test

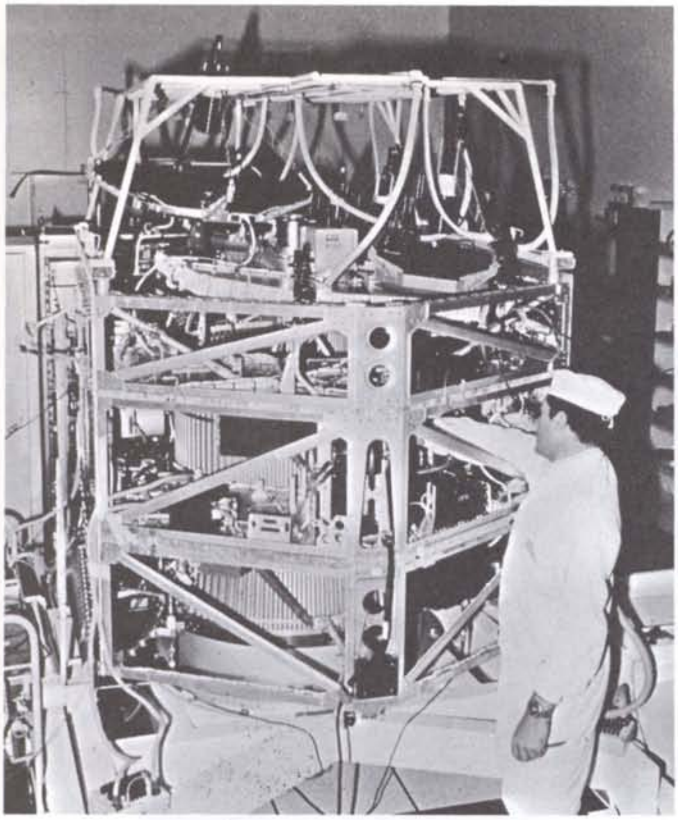


Figure 3 – OTS engineering model under test at MATRA, Toulouse.

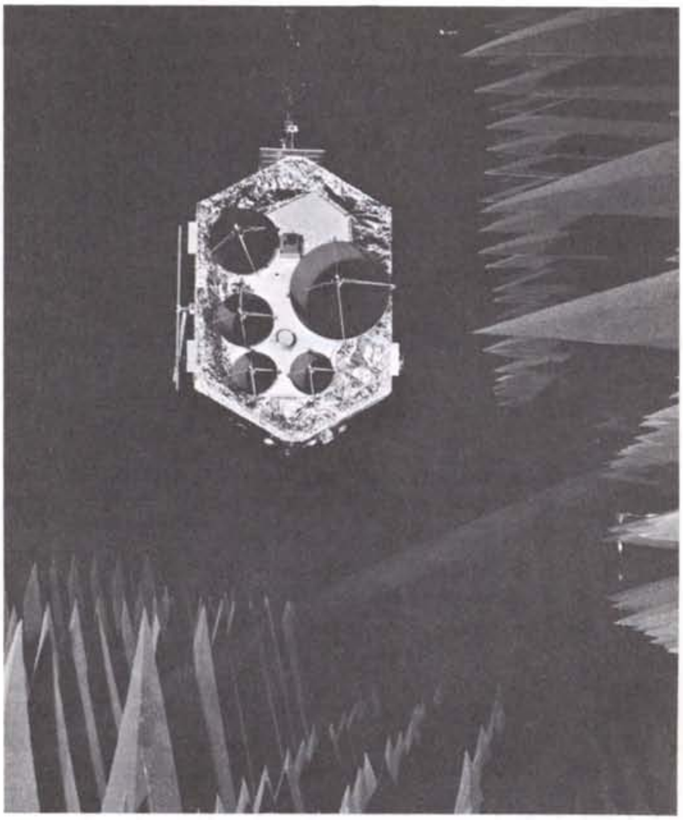


Figure 4 – OTS in the anechoic chamber at HSD, Stevenage.

programme carried out in the anechoic chamber at HSD, Stevenage (Fig. 4).

In summary, the engineering-model test programme demonstrated:
- the viability of grounding the primary bus
- satisfactory secondary grounding
- excellent power-bus stability (tests with the repeater in TDMA also showed the bus to be unaffected by this mode of operation)
- compatible design interfaces for all subsystems
- satisfactory predictions of system performance.

QUALIFICATION MODEL

A comprehensive series of environmental tests was carried out on the OTS qualification model, including:
- sine vibration
- spin
- acoustic noise vibration
- centrifuge acceleration
- solar simulation.

Each major test phase was preceded by an integrated systems test which verified correct functional behaviour of the satellite, with a final IST at the end of the test sequence.

A significant problem was encountered during solar-simulation testing which was traced to a major heat-dissipation unit whose heat-transfer characteristics had been radically changed in the course of satellite modifications to the 3914 standard. Trimming of the radiator panel brought temperatures back to acceptable levels.

FLIGHT MODEL

The flight-model test programme, which was more limited than that on the qualification model, was accomplished with complete success.

CONCLUSIONS

The OTS development programme is now virtually complete and it has given the industrial team an opportunity to establish a sound and proven working relationship with ESA. The members of the Consortium now look forward to the application of the experience and expertise gained in the course of the programme to ECS and other ESA programmes, as well as in the World market. □

The Orbital Test Programme

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S. Hånell, Directorate of Communication Satellite Programmes, ESA

When OTS sets out on its journey towards the geostationary position that has been assigned to it, it will mark the beginning of a new era for our continent, that of communications satellites dedicated to Europe's needs. In addition to those who have contributed in one way or another to the construction of the satellite and are anxious to see it at work, there will be those who have been looking forward to using it and have been preparing for just that for months or even years. At the time when the configuration of OTS was defined, in 1972, the picture we had of its programme of utilisation in orbit was very vague and, in fact, very different from what it is today. Although the emphasis is still on the role of OTS as a forerunner of the future ECS satellites, the actual functions this first satellite is going to perform are now better understood. Originally the scope of what is called the Orbital Test Programme (OTP) covered only those tests concerned with verification of the satellite's performance in orbit and which are ESA's responsibility. It was later expanded to include a very comprehensive programme of experiments defined by the CEPT administrations, extending from relatively simple transmission tests initially to full-scale routing of live telephony and television traffic on a preoperational basis in 1980-81. More recently, the OTP has grown further with the inclusion of another group of experiments not directly connected with the classical mission of ECS, which is restricted to trunk telephony and television transmission. A number of novel applications for communications satellites have indeed been identified in the course of the last two or three years and interest in conducting relevant experiments with OTS has led to a number of projects currently in the course of implementation.

The objectives pursued by ESA in carrying out the Orbital Test Programme are threefold. In addition to assisting the European P & T Administrations and the European Broadcasting Union (EBU) in preparing themselves for the implementation of the ECS system, which is a first concrete target, the Agency is striving to build up its competence in designing communications satellites in readiness for undertaking further programmes in the coming years. It is therefore essential to derive the maximum of practical experience from the OTS experimental phase and to draw from it lessons for future projects. But it is also ESA's task to investigate possible new utilisations of communications satellites and OTS provides a unique opportunity to assess the feasibility of attractive proposals by means of practical experiments.

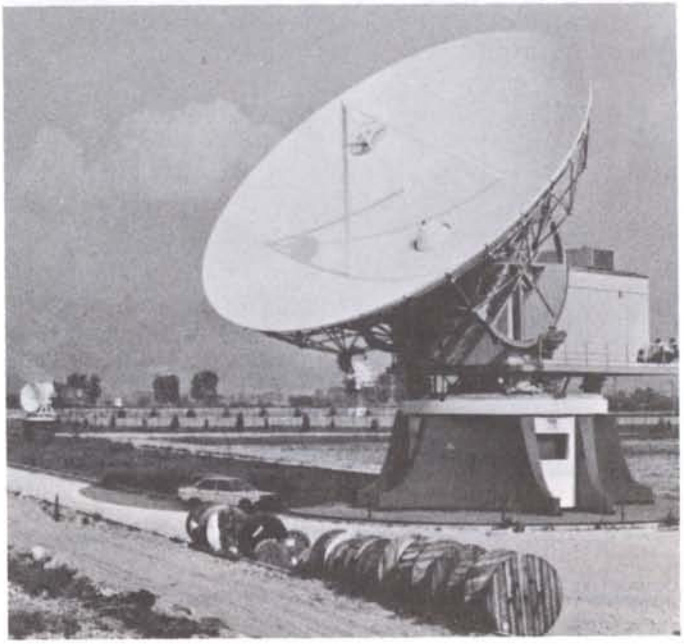

Figure 1 – The two 11/14 GHz antennas at Fucino, Italy.

The experiments that constitute the Orbital Test Programme can be conveniently grouped into four categories:
- verification of satellite performance in orbit
- transmission tests related specifically to implementation of the ECS system
- measurements of propagation effects (atmospheric attenuation and polarisation disturbances)
- experiments related to new applications.

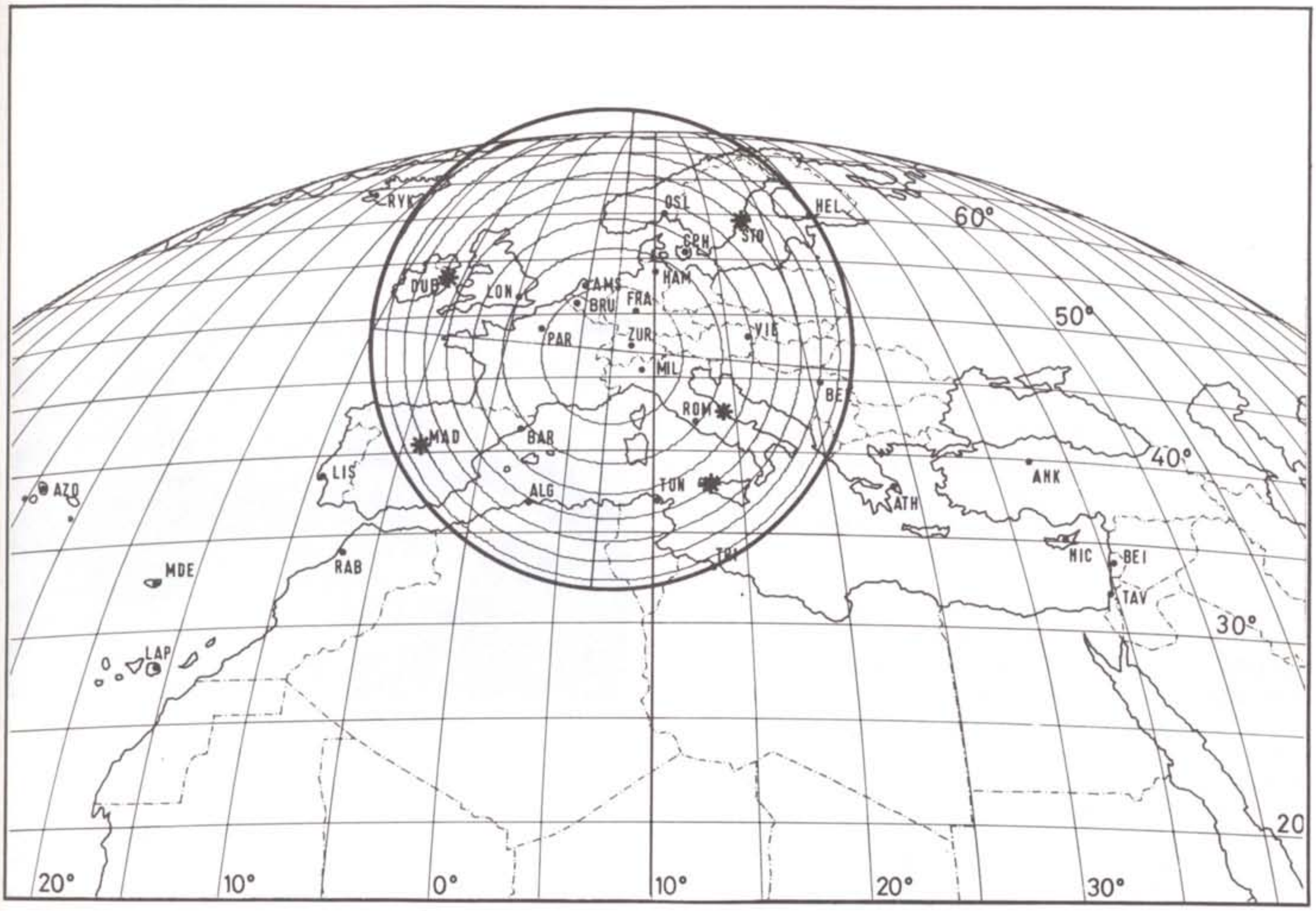

Figure 2 – Locations of the four ESA fluxmeter stations, and the SCTS (Fucino, near Rome).

SATELLITE PERFORMANCE TESTS

The purpose of the satellite tests is to validate the design of the satellite and to verify the performance in orbit of its payload and all of its subsystems. These tests will mainly be carried out using the Satellite Control and Test Earth Station (SCTS), a facility owned jointly by the Agency and Telespazio and which shares the same site as the Italian Intelsat stations at Fucino. The SCTS, a detailed description of which has been given in a previous issue of the Bulletin*, includes two antenna heads (reflectors 17 and 3 m in diameter), both of which can be used for transmitting at 14 GHz and receiving at 11 GHz (Fig. 1). Several other small stations owned by ESA and located in various countries in Europe will also be involved in the satellite tests.

A great deal of the data sought will be obtained by means of passive tests using only information gathered in a routine manner via the telemetry channel going to the Control Centre at ESOC (Darmstadt) via the SCTS in Fucino. These tests will be mainly concerned with verifying the performance of the service subsystems (power generation, thermal control, attitude and orbit control, etc.) to check their behaviour under all operating conditions. They will not interfere with other experiments and will be conducted throughout the lifetime of OTS.

There will also be active tests which will preclude the use of the satellite for other purposes. These will be concerned with measurements on the communications payload and they will require the switching and loading of the repeater chains by test signals and changes in satellite attitude to determine the characteristics of its antennas. Active tests will be concentrated into the eight months following the arrival of OTS on station. The most important of them will be repeated at six monthly intervals, occupying the satellite for a few days each time.

Active tests will be of three kinds. The first group will be aimed at checking the performance of the repeater

* 'The Satellite Control and Test Earth Station at Fucino', ESA Bulletin No. 5, May 1976.

package when first in orbit to verify that specifications are met, and subsequently at looking for diurnal variations, life degradation and eclipse effects. Typical characteristics to be measured include output power, noise figure, frequency stability, amplitude/frequency response and group-delay/frequency response. The behaviour of the repeater chains as transmission channels will also be monitored by measuring their performance when loaded with digital and television test signals.

The second group of tests is related to the incentive scheme that forms part of the contract between ESA and the MESH Consortium for the development of OTS. The contractor's profit is linked, inter alia, with the power flux that OTS delivers to selected sites in Europe. To make the scheme sensitive to beam pointing accuracy, four measuring points have been chosen at the edge of the Spotbeam, namely Dublin, Stockholm, Milo in Sicily and Villafranca del Castillo in Spain (Fig. 2). For the Eurobeam antennas, which are not so sensitive to pointing accuracy, measurements are to be made only at the SCTS. A byproduct of the power-flux recordings made around the edge of the Spotbeam coverage area will be a very precise measure of beam pointing, from which it will be possible to derive additional information on the behaviour of the satellite's attitude control system, for instance during stationkeeping manoeuvres.

Turning now to the third group of tests, their aim will be to verify the characteristics of the satellite antennas (gain, beam shape and polarisation discrimination) using the SCTS, the four small stations set up for the incentive measurements, and a fifth (transportable) station which will become operational early in 1978. During these tests, the satellite's attitude will be modified in a cyclic manner so that the antenna beams scan the Earth in an east-west direction, the effect being to make a number of cuts through the radiation patterns which can then be reconstructed and compared with those measured before launch.

ECS-RELATED EXPERIMENTS

The future ECS system will differ in many respects from existing commercial satellite communications systems. The main areas in which it will innovate are the use of frequencies in the 11 and 14 GHz bands, the adoption of digital transmission techniques on a large scale, the implementation of multiple access by the earth stations on a time- rather than frequency-division basis, and the re-use of the spectrum by means of dual-polarisation antennas. Communications experiments of various degrees of complexity will be carried out with OTS in order to test the new techniques and to validate the design of the system as a whole by verifying that earth stations can communicate efficiently with each other. In addition to the SCTS in Fucino, three other large earth stations will take part in these activities; they are at Bercenay-en-Othe near Troyes in France (French PTT Administration), at Usingen near Frankfurt in Germany (Deutsche Bundespost) and at Goonhilly Downs in Cornwall, UK (British Post Office). All are designed such that they can be used later in the ECS network; the diameters of their antennas range from 15 to 19 m. ECS-related experiments will be the responsibility of the national administrations involved and will be co-ordinated by a body set up specially by the CEPT. They are described extensively in the next article. ESA's contribution to this part of the programme will be to collect all relevant information regarding the performance of the satellite and its communications payload, and to gather data on propagation conditions. The SCTS at Fucino is provided with monitoring facilities, the output of which is collected and recorded automatically on tape for later processing by computer. Figure 3 shows the data-logging equipment,

Figure 3 – Data-logging equipment and minicomputer at Fucino.

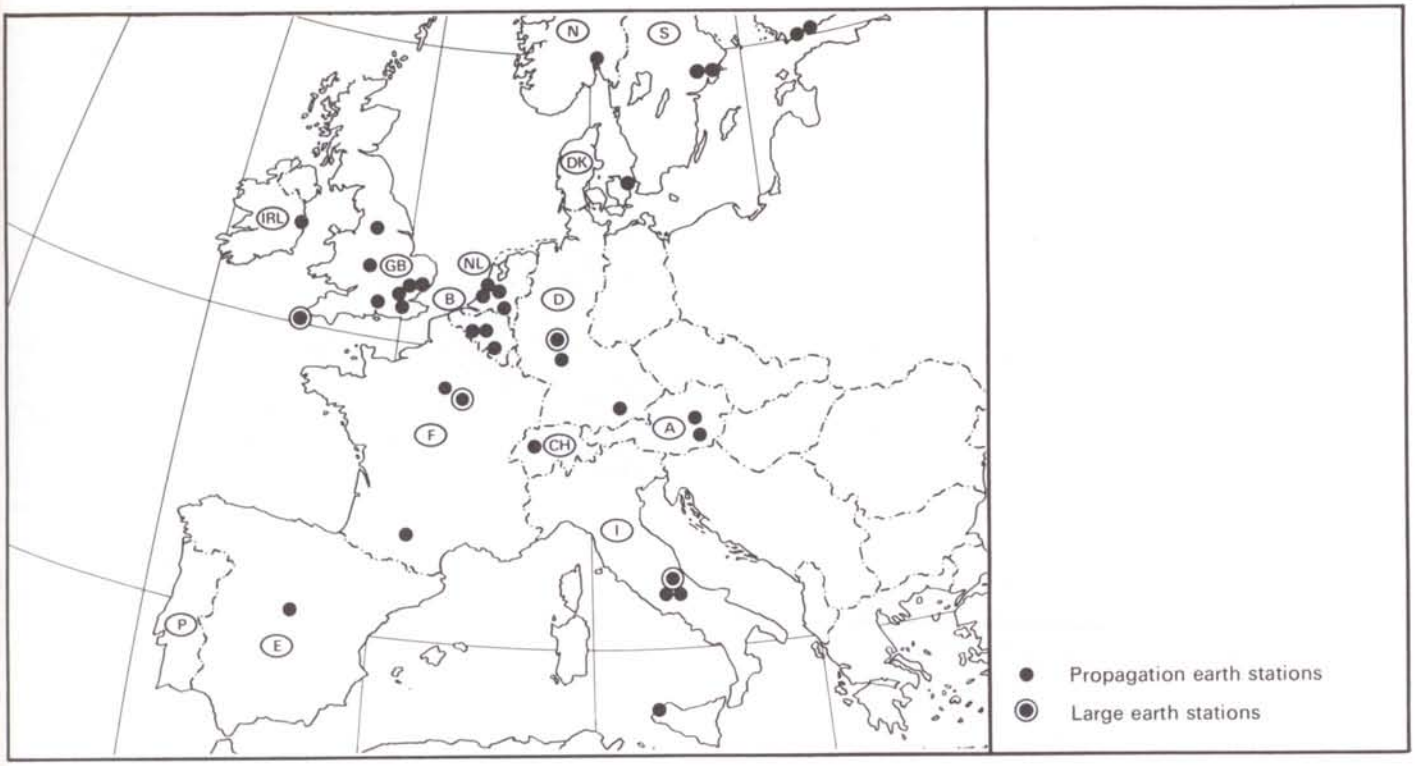

Figure 4 – Satellite earth stations planned or already under construction.

which includes a Hewlett-Packard 2100 A minicomputer with various peripherals. Important results expected from analysis of the data are long-term statistical information on the performance of the satellite channels and correlations with atmospheric disturbances, particularly rain and snow falls. The CEPT programme of experiments will start immediately after completion of the first eight months of ESA tests and will continue, in principle, until 1981, when the first ECS satellite will be ready for operations.

PROPAGATION MEASUREMENTS

OTS carries a separate repeater package, known as Module B*, intended primarily to satisfy the requirements of the many P & T administrations, broadcasting agencies, universities and research organisations interested in studying the propagation of radio signals at 11 and 14 GHz in the atmosphere. Given the vital importance of these studies for the design of future satellite systems operating at these frequencies, propagation experiments have been given priority as far as the use of Module B is concerned. They will begin as soon as OTS is on station. The stations required for these experiments can be relatively simple and inexpensive. About 30 are currently under construction or are already complete (Fig. 4). Most are equipped with antennas some 3 m in diameter, but some go up to 14 m, and all are expected to be ready to take part in the measurement campaign that will start in spring 1979 under the co-ordination of the CEPT.

ESA has been active since 1972 in the collection of propagation statistics by means of radiometers**. In the absence of a satellite emitting signals at 11 and 14 GHz, the only method of measuring atmospheric attenuation has been an indirect one, by measuring the radio noise of the sky in the direction of a hypothetical satellite and deriving the attenuation by calculation. Five of these radiometers have been refurbished and integrated into the SCTS and the four fluxmeter stations where they will be used for the collection of propagation data and for incentive-scheme measurements (Fig. 5). The data will be collected automatically and recorded on tape with a precise time reference for later processing on a central computer.

NEW APPLICATIONS FOR COMMUNICATIONS SATELLITES

Satellite communications have a number of unique features that originate from the geometry of the satellite system and its physical characteristics. They relate to the

* See the earlier article entitled 'The Orbital Test Satellite'.

** 'Mesures et expériences de propagation dans le cadre du programme ECS', ESA Bulletin No. 5, May 1976.

fact that the repeater station at its apparent fixed location 36 000 km above the Earth's surface is in sight of all terminal stations, which can therefore use it as a single relay point for all their transmissions. Some of these features make satellite links particularly attractive for certain applications:

(a) Since satellite-relayed signals can be received simultaneously by many terminals, space links lend themselves easily to applications involving transmissions to multiple destinations. In addition to the well-known case of direct broadcasting of television and radio programmes to the general public, one must also consider such services as conference connections and teledistribution of information to be printed.
(b) For communications with points or areas not easily accessible by conventional means, satellites may be the best or even the only solution. This has already been demonstrated by Marisat for the maritime service, but it also applies to the fixed service, for instance for oil platforms situated far offshore or for islands in the polar regions, such as Spitzbergen (Svalbard).
(c) Unlike the repeater stations of terrestrial radio-relay links which are bidirectional, satellite repeaters are unidirectional and are unaffected by unbalanced loading caused by one-way traffic. This feature is of particular interest in the case of data transmission which is often unidirectional or highly imbalanced.
(d) Satellite links can be made available in time-sharing mode to different pairs or groups of terminals; they can therefore be used more efficiently than terrestrial links for services that require intermittent connections.
(e) The maximum transmission bandwidth provided by a satellite channel is much broader than currently available via terrestrial networks on a European or even national scale. In most practical cases, satellite links are the only means of implementing a wideband connection quickly between points more than a hundred kilometres apart.

Prospective studies of new fixed-service satellite applications (as distinct from maritime and broadcasting services) have so far shown that there are two main areas for which space links appear attractive. The first is data transmission at megabit-per-second rates, particularly in those cases where the transmission channel can be used in a time-sharing mode by different groups of users. Good examples are real-time interconnections between distant computers, transfer of bulk data between computer centres or databanks, and transmission of information to be printed, e.g. documents or newspapers. None of these services can be furnished to any significant extent by present terrestrial networks in Europe, where the maximum transmission speed is still limited to a few kilobits per second.

The second kind of application that merits consideration is communications with oil rigs far offshore in the North Sea. Here the problem for terrestrial systems is not one of bandwidth, but one of cost or technical feasibility (e.g. troposcatter links) or of insufficient reliability (e.g. high-frequency links).

A communications experiment between the UK mainland and a North-Sea oil rig using OTS is presently being considered. Discussions between the parties concerned are still in an early stage and it is not yet possible to describe this experiment in detail, but it will involve small terminals with 3 m antenna reflectors. In the data-transmission field, on the other hand, a few proposed experiments have already reached the planning stage.

THE CERN EXPERIMENT

CERN, the European Centre for Nuclear Research in Geneva, plays host each year to hundreds of scientists, drawn from some 150 universities and institutes in western Europe, who conduct high-energy physics experiments with the centre's large accelerators. These experiments produce huge volumes of data which require several days of computer time for analysis. Much of this work must therefore be done back in the experimenters' individual laboratories, away from CERN. This leads to much travelling, long delays and high costs, and it is clear that if high-speed data links were available between CERN and the national centres, visiting experimenters would have immediate access to their home computers and could work much more efficiently. Such data links could be provided easily by satellite and ESA has proposed an experimental service via OTS. The aim is to set up a 1 Mbit/s link between CERN and several national

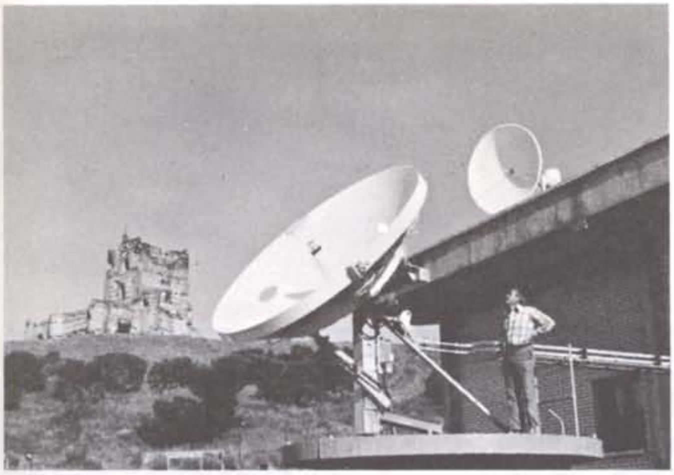

Figure 5 – Fluxmeter station at Villafranca, Spain.

high-energy physics centres in the UK, in West Germany, in France and in Italy. The proposal has found support from the EEC authorities in Brussels, which will finance the CERN terminal, and from the national administrations in the four countries involved. ESA will make the satellite available at no charge.

The earth stations required will be small and will be similar in general appearance to that shown in Figure 5. Their main characteristics are summarised in Table 1.

TABLE 1

Transmitter	200 W / 14.5 GHz
Receiver	Tunnel-diode amplifier front end / 11.7 GHz
Antenna	3 m diameter / manually steerable
Data rate	1 Mbit/s
Modulation	Two-phase PSK

Present plans are to start procurement activities before the end of the year so as to be ready for experiments in 1979.

THE ESA EXPERIMENT

ESA has also proposed another experiment involving the use of OTS to interconnect its various establishments. Two kinds of experimental service are envisaged. One is the setting up of high-speed data links between the large computers installed at ESOC, ESTEC and ESRIN with a view to increasing the efficiency of use of these expensive machines. The other is a transmission facility for the rapid exchange of documents and other printed material, as well as still and live pictures. The latter facility may eventually be expanded into a videophone service between all Agency centres. ESA's objectives in setting up this experiment are twofold: to investigate the suitability of satellite links for relaying digital data at

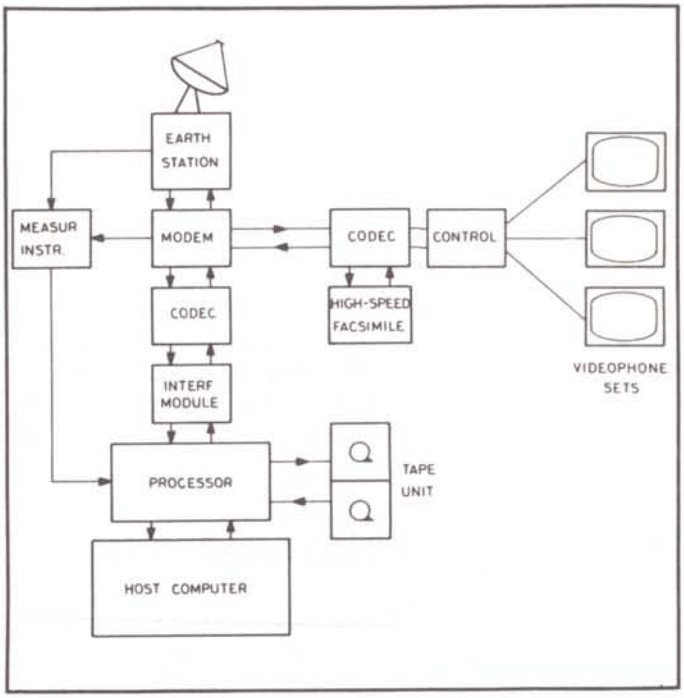

Figure 6 – Block diagram of experimental ESA terminal.

megabit rates between small terminal stations, and to assess the benefits that an organisation as geographically dispersed as the Agency could derive from such services if P & T Administrations could provide them on an operational basis.

The ESA experiment will be carried out in parallel with that of CERN and will be technically compatible with it in all respects. The earth stations will be of the same type and the characteristics of the signals relayed by the satellite will be identical. Both experiments will require sporadic access to OTS and will operate in a time-sharing mode.

The ESA experiment will be implemented in several phases, starting in 1979 with a terminal at ESTEC and one at ESRIN. Further terminals will subsequently be installed at ESOC, at Head Office and possibly also at Villafranca. A complete terminal station of the sort currently envisaged for ESTEC, ESRIN and ESOC is shown in Figure 6.

OTHER DATA-TRANSMISSION EXPERIMENTS

Other experiments are currently in the planning stage. In Sweden, for instance, a project is under study, the aim of which is to evaluate satellite links as carriers for information to be printed at remote locations. Plans are to establish a high-speed data channel via OTS to print a Stockholm newspaper at other locations in Sweden. The Swedish Telecommunications Administration is co-operating with ESA in this venture.

Interest in data transmission by satellite continues to grow and further proposals are expected to be put forward in the near future. DFVLR in Germany, for instance, has declared its intention to join this part of the OTS experimental programme.

TELEVISION-BROADCAST EXPERIMENTS

OTS is not designed for direct broadcasting applications, but it nevertheless offers interesting possibilities in this area. ESA has proposed that one of the repeaters associated with the Spotbeam antenna could be used to retransmit a television programme, concentrating the satellite radiated power into a much narrower bandwidth than the nominal 120 MHz so that the power density will be sufficient to permit reception by relatively small terminals. In fact, if one is prepared to accept a reduction in propagation margin, reception of a useful signal is possible under most conditions with an antenna 3-5 m in diameter. Although the cost and size of such terminals is still higher than the general public can afford, it is low enough to attract the interest of many broadcasting agencies in Europe and in North Africa, who welcome the opportunity to conduct their own experiments with this new medium. It is planned to test various kinds of equipment for individual and community reception, such as low-noise FET amplifiers and threshold-extension demodulators, to study the relative merits of different transmission techniques, to investigate the influence of parameters and propagation effects on reception quality, and in general to make progress in the definition of future European satellite-broadcasting systems. Figure 7 shows the kind of station required for these experiments; this particular one, which has a 4.6 m antenna reflector, is being installed at the University of Louvain-la-Neuve near Brussels.

MANAGEMENT OF THE PROGRAMME

The Orbital Test Programme will comprise a large variety of experiments involving the participation of many organisations initially operating some 30 to 40 stations. It is therefore essential that all activities be properly co-ordinated. The management scheme to be implemented is based on an agreed division of responsibilities between

Figure 7 – Satellite earth station at the University of Louvain, near Brussels.

ESA and the CEPT; the Agency will concern itself with the satellite tests, whereas the CEPT will be responsible for co-ordination of the communications experiments. Since the two categories of tests will be separated in time, the two organisations will assume their management functions according to a pre-established schedule. In principle, ESA will take charge during the first eight months of OTS's life in orbit and again at regular half-yearly intervals for short periods when routine satellite tests have to be performed. The CEPT will normally be responsible for co-ordination at other times.

The management structure is shown schematically in Figure 8. Overall plans and broad schedules will be drawn up by the executive bodies of the two organisations.

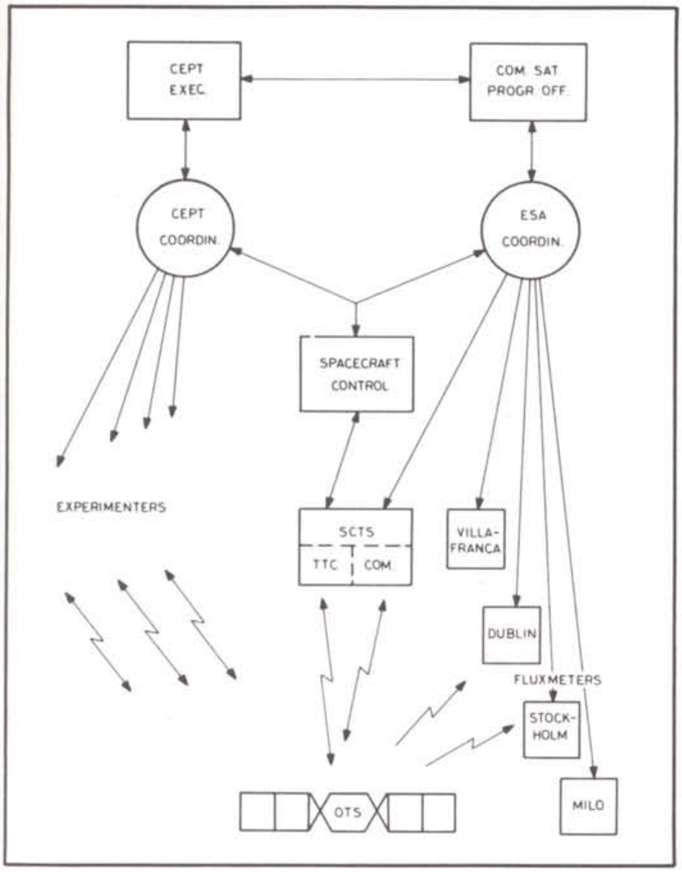

Figure 8 – The OTP management structure.

Detailed implementation of these plans will then be carried out by the 'duty co-ordinator', who will issue the necessary instructions to the spacecraft control centre and to the experimenters concerned.

As far as the ESA tests are concerned, there will be two main centres of activity. One will be the Spacecraft Control Centre at ESOC, which will control the satellite's configuration and gather information on its service functions, via telecommand and telemetry channels passing through the SCTS. The other will be Fucino, where most of the communications equipment is concentrated and where the measurements on the payload will be made. The latter task will be performed with the assistance of Telespazio staff in charge of the station's operation. There will be constant liaison with the other Agency stations at Villafranca, Dublin, Stockholm and Milo. For the last three, the work will be conducted with the co-operation of the Irish P & T, the Swedish Telecommunications Administration and the Italian Consiglio Nazionale delle Ricerche, respectively. It is expected that, as time goes on, other non-ESA stations will participate in these measurements, subject to the agreement of the local experimenters.

CONCLUSION

OTS will be used for two kinds of experiments, namely those requiring large earth stations with antennas 15-19 m in diameter, of the type needed by the P & T Administrations for the ECS system, and those for which much simpler and cheaper terminals are sufficient. Two large stations are ready for service and two more are nearing completion. Small stations are being built in large numbers. Thirty-three are under way or have already been completed. The total cost of this infrastructure is currently estimated to approach 40 MAU, i.e. roughly half the cost of the main development contract for OTS, and indications are that, as interest in OTS and ECS continues to grow rapidly, further considerable investments will be made by P & T Administrations and other organisations in the coming months.

Clearly, OTS carries the hopes of many Europeans anxious to exploit this new mode of communication. P & T Administrations see it as a preliminary version of ECS, with which they expect to find ways of improving the quality of their public telecommunications services. Other organisations, including the Agency itself, welcome the opportunity to explore the new technologies and techniques that could subsequently find worthwhile applications in everyday life. □

The CEPT Programme of Experiments for OTS

P. Barthmann, Permanent Nucleus of CEPT, Paris

When, in the early seventies, ESRO began to think seriously about a European communications satellite system, the national Administrations that are members of the CEPT (Conférence européenne des Administrations des Postes et Télécommunications) set up a 'Permanent Nucleus' composed of eight telecommunications engineers from six European countries to help and advise. One of the problems faced was to formulate the communications payload for OTS in such a way that it corresponded well to the requirements of the Administrations, requirements resulting mainly from the fact that this was to be the forerunner of a future communications satellite that would form part of the inter-European telecommunications network.

OTS will enable many new communications techniques to be tried and tested and the CEPT has developed a wide-ranging two-year test programme to study them and their effects on telecommunication signals. The programme will start with basic tests and will develop progressively into a study of the handling of the operational traffic. In this respect, OTS can be seen as the forerunner of a future European Communications Satellite (ECS) system, and the Orbital Test Programme (OTP) as paving the way for the introduction of ECS.

Before going on to describe the CEPT test programme, it may be useful to explain very briefly some of the techniques envisaged for ECS and to be tested on OTS.

Digital Transmission Techniques

In telephony, it is sufficient to transmit only the speech frequencies in the 300–3400 Hz band. The analogue electrical signal from the microphone can either be transmitted as such or, if the signal is sampled rapidly over very short durations, as a number of bits or pulses (typically a digital flow of 64 kbit/s for a speech signal) which can be processed at the receiving end to reconstitute the original analogue signal. This process is called Pulse-Code Modulation (PCM). Its outstanding advantage is a high resistance to interference and noise. Also, PCM encoded signals can be further sampled and treated so that many simultaneous conversations can be multiplexed into the same radio-frequency channel.

Frequency Re-use by Polarisation Discrimination

Electromagnetic waves can be polarised so that the electrical vector is confined to one plane, and such a signal will not be received by an antenna so placed that its electric field plane is orthogonal to the electrical vector of the incoming signal. This orthogonal polarisation makes it possible to use a single frequency for two channels. In practice, a decoupling of 30 dB (one thousandth part) between such channels can be achieved.

Time-Division Multiple Access (TDMA)

In the past, multiple access to a satellite system has been by frequency division, with several signals differentiated by frequency passing together through a satellite repeater and its nonlinear amplifier. This results in intermodulation and thus severe system losses. With TDMA, multiple access is afforded by time instead of frequency division. Rather than assigning different segments of the repeater bandwidth full-time to different earth stations, the full bandwidth is allotted to each earth station in turn for a period of about 100 μs (a typical period for the transmission of about 250 telephony channels in a 60 Mbit/s system). The transmissions from the various earth stations have to be so co-ordinated that their signals, called 'bursts', do not overlap, and this calls for considerable complexity in the earth-station equipment.

Digital Speech Interpolation (DSI)

In telephony transmission which uses a forward and a return channel, one of the channels is idle for more than half of the time. Digital speech interpolation enables the same channel to be used for both forward and return transmission by allocating it to the active speaker, thus increasing system capacity by a factor of at least 2.

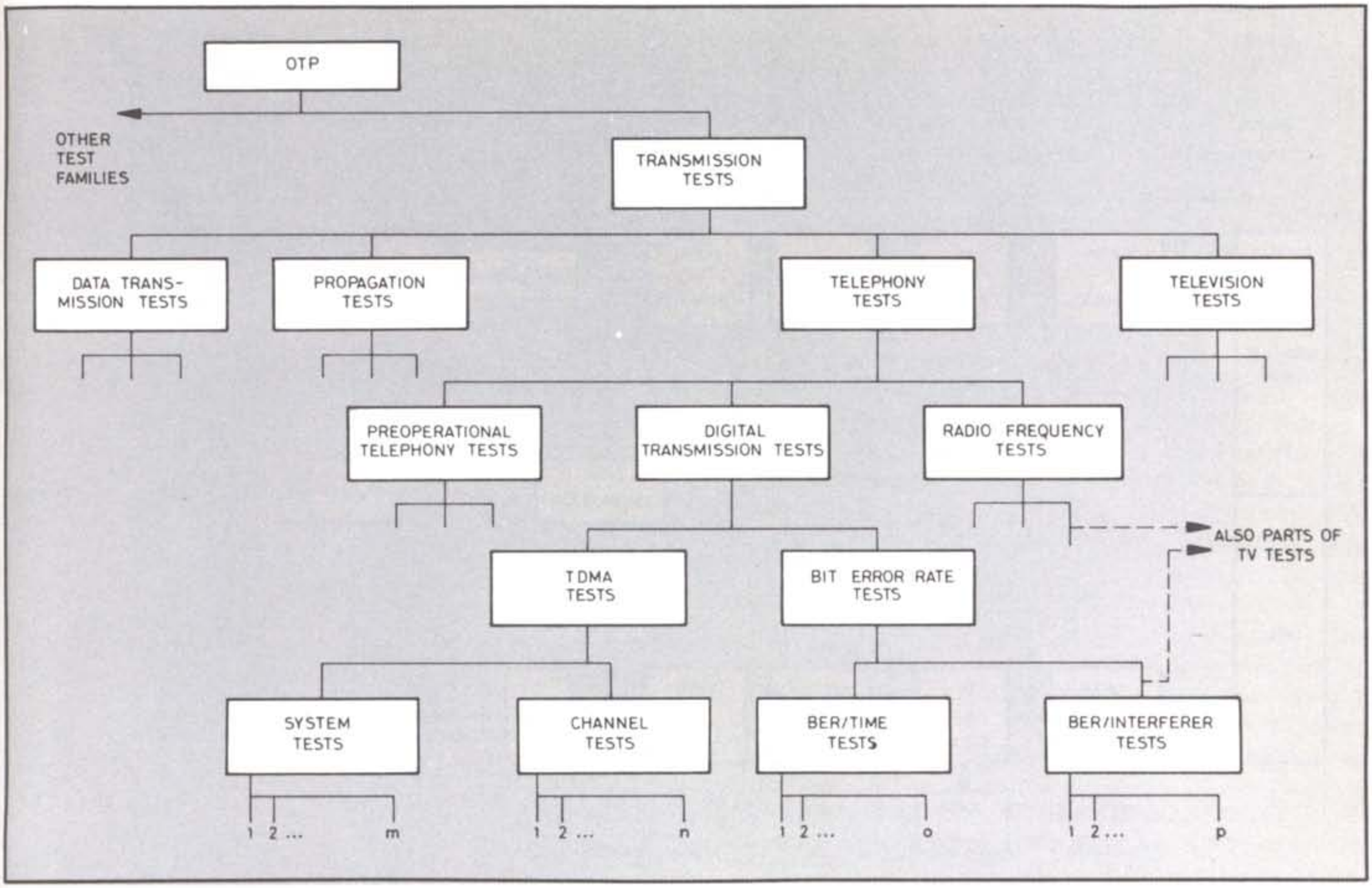

Figure 1 – The CEPT communications tests.

TEST APPROACH

OTS has been designed:

- to validate the design and performance of a platform and payload which anticipates most of the features of a future ECS system
- to study propagation effects in the new radio-frequency bands allocated to fixed services
- to evaluate the performance of transmission techniques to be used on ECS, such as digital transmission, TDMA and frequency re-use by cross-polarisation
- to prepare for the operational introduction of the ECS system into the European communications network.

The satellite tests are primarily the concern of ESA and are covered in the preceding article. We will deal here only with the transmission tests and the preoperational tests for which the P & T Administrations are responsible. The various aspects of these tests are interrelated in so far as they all affect the signal quality and they have to be co-ordinated and directed to the production of reliable information in those areas that are of particular interest for an operational communications system.

THE COMMUNICATIONS EXPERIMENTS

Whilst, as has been mentioned, there is an inter-relationship between all the tests to be conducted, each series of communications tests is independent of the others. They can be grouped into four main categories:

- telephony measurements
- television measurements
- propagation experiments
- other experiments, in particular data transmissions and television broadcasts.

The basic performance of the OTS repeater and beacon will be established by 13 sets of tests (Fig. 1) covering radiated power, frequency response, frequency-generator instability, polarisation decoupling by antennas, thermal-noise generation, etc. The results of these tests, which will be checked against pre-launch values, will be used as primary reference measurements. As such, some of them, for example the measurements of co-channel interference, will have to be repeated prior to particular tests in order to take into account variations in satellite parameters.

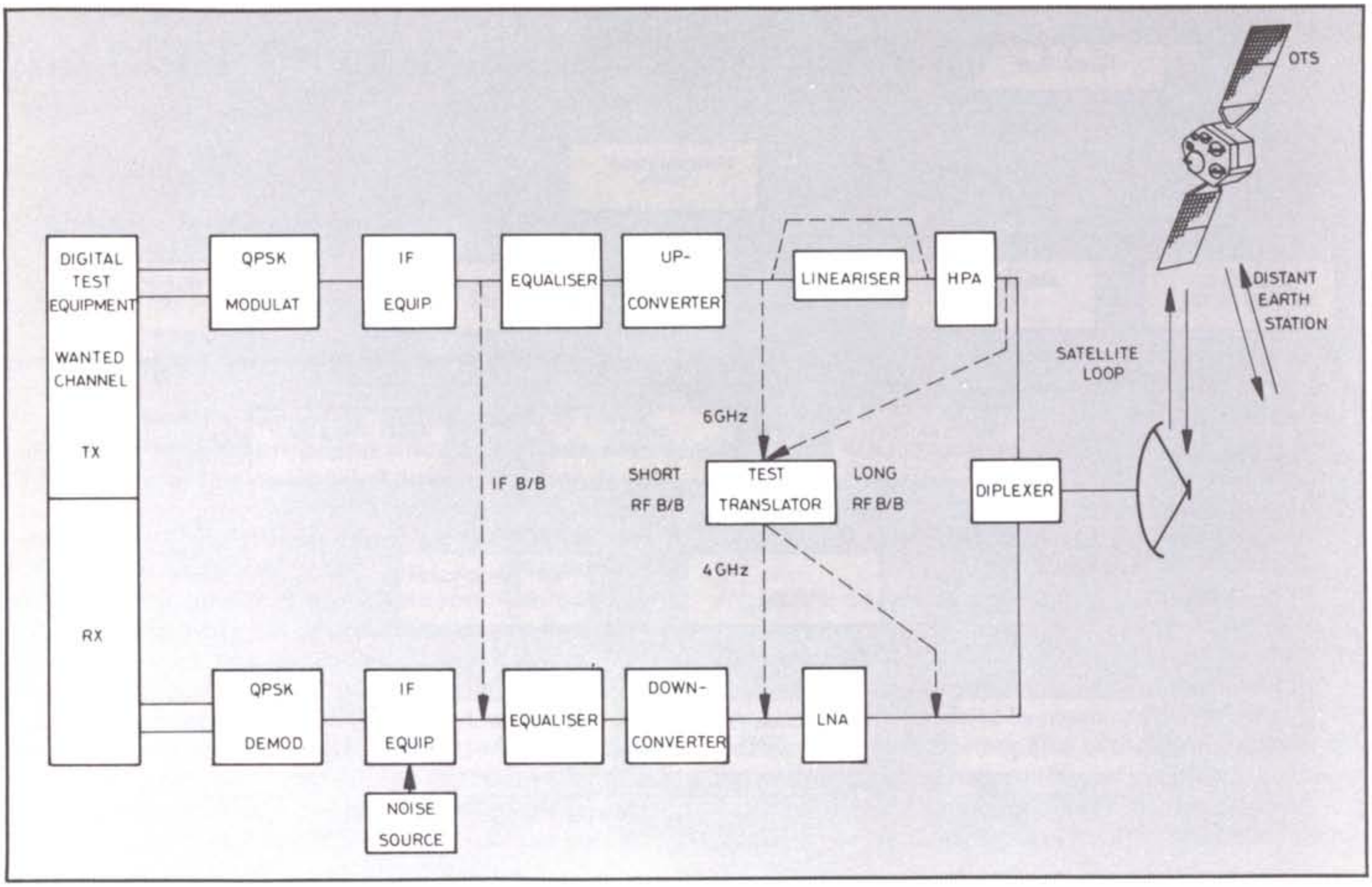

Figure 2 – Configurations for the digital transmission tests.

TELEPHONY TESTS

These will be carried out by the P & T Administrations of France, Germany, Italy and the United Kingdom using large earth stations with antennas 14.5 to 19 m in diameter.

Digital Transmission Tests

So that the effects of the various elements in the system can be identified:

- the configuration under test will first be limited to basic equipment and then extended step-by-step, and
- interference and noise will be generated artificially and injected into the signal path.

The first tests will be performed with the Phase-Shift-Keying (PSK) modulator linked to the demodulator (IF back-to-back mode in Fig. 2) and with continuous signals. Various levels of thermal noise will then be injected and the Bit Error Rate (BER) measured.

In the next step signal bursts will be transmitted. The demodulator then has to acquire the incoming signal's carrier and clock frequencies before it can demodulate and detect the baseband signals. This stage will determine the system loss due to the implementation of the modem.

Next to be investigated will be the signal degradation by the earth station's high-power transmit amplifier (HPA). This, being either a Travelling-Wave-Tube (TWT) or a klystron amplifier, introduces signal amplitude and phase distortions, so that the BER will be greater than in the previous test for the same signal-to-noise ratio.

Since the degree of distortion in the system depends on the drive level of the amplifier, the BER also depends on the HPA operating point. The amplifier's maximum output power cannot be used because as saturation is approached the distortions increase faster than signal power. It is hoped to overcome the major part of this loss in performance by the introduction of a 'lineariser' in front of the HPA to compensate for the majority of its amplitude and phase distortions. The importance of this experiment lies in the fact that successful linearisation would allow the broadband characteristics of a TWTA to be used. It could then feed several repeaters, thus dispensing with the need to provide several costly TWTAs in the earth station.

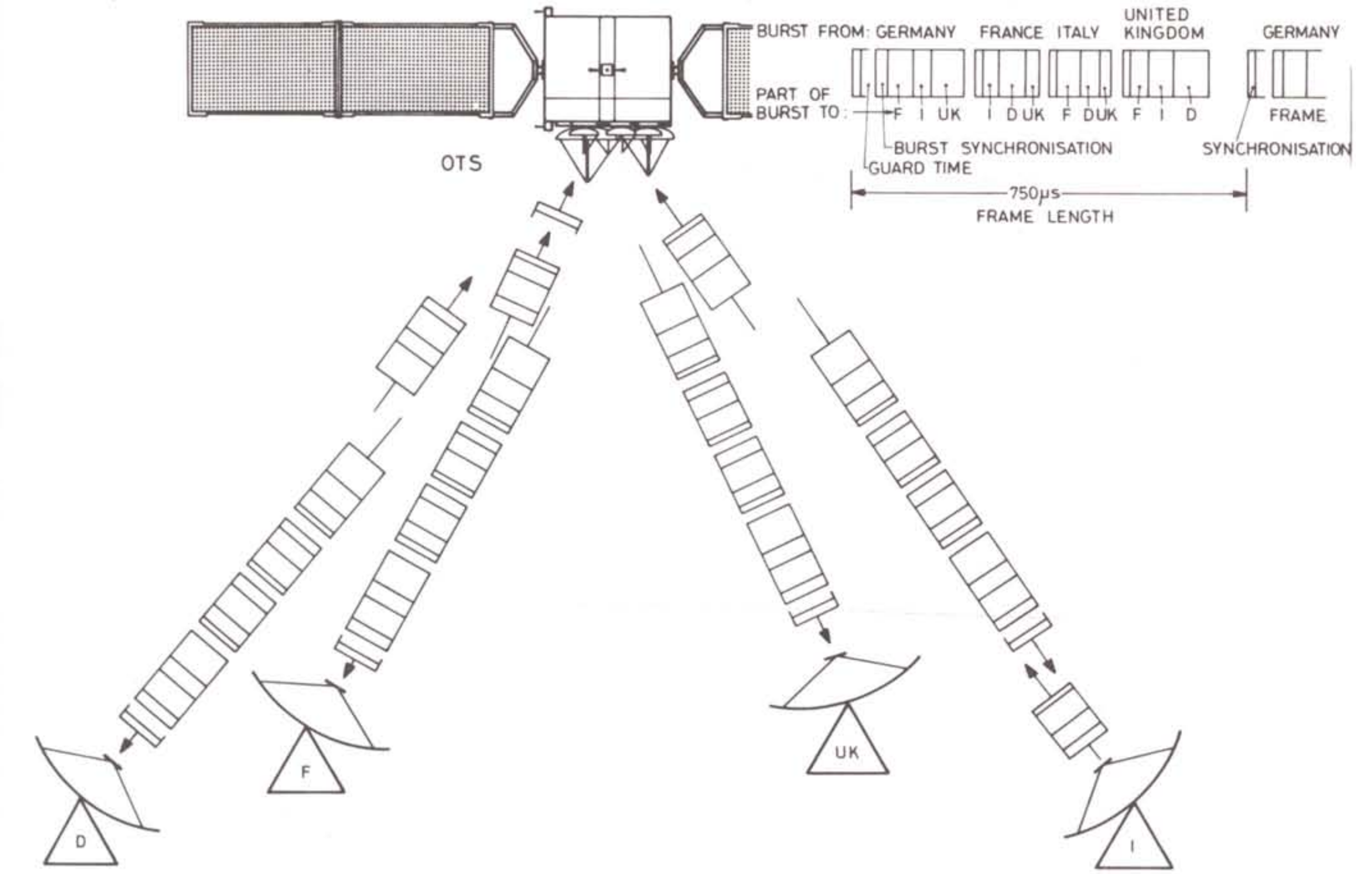

Figure 3 – Schematic representation of the TDMA tests to be conducted during the Orbital Test Programme.

In the next phase of testing, the test signal will be transmitted via the satellite repeater which contains another travelling wave tube. Accordingly, the same optimisation as for the earth station HPA will be carried out to determine the best operating point. This optimisation is of great importance in ensuring most efficient use of the system.

Another important series of tests will investigate co-channel interference when employing re-use by polarisation discrimination. In good weather, this interference arises only from imperfections in the earth-station and satellite antennas and from neighbouring satellite or radio links. Bad weather, however, displaces the plane of polarisation of the signal channel, yielding a noticeable increase in interference. Since it is not practicable to await the appearance of the appropriate meteorological conditions for particular test periods, this kind of interference must be artificially simulated. As the effects on the uplink are not necessarily representative for the downlink, the interferer will be injected into the signal path by either the transmitting or the receiving earth station, using an independent signal source in order to avoid correlation between the wanted signal and the interferer.

TDMA Tests

These tests are of four types:

- acceptance tests on each earth station (these do not require the use of OTS)
- tests to verify that the four terminals (built by three different consortia) are mutually compatible
- verification of station performance criteria both in normal operation and under simulated failure conditions
- investigation of the system in steady-state operation.

Figure 3 shows the test configuration to be used with the German station transmitting a reference burst as well as its data burst. Such a reference or synchronisation signal is vital to the control of all the earth stations' transmissions to within an accuracy of 50 ns. Circumstances that could affect synchronisation and which therefore have to be investigated include:

- a period of severe degradation of signal-to-noise ratio (caused, for example, by a thunderstorm) during which telephony may no longer be possible at all despite system synchronisation not having been lost
- interruption of the reference burst transmission for

some seconds to verify that flywheel synchronisation is functioning correctly (housekeeping tasks)
- a slip in the reference burst, which would result in all data bursts slipping to exactly the same degree
- replacement of the German reference station by, say, the Italian station, which must then produce its synchronisation burst at exactly the same point in the TDMA frame if the system is to remain synchronised
- forced cessation of transmission by a station followed by re-acquisition of synchronisation.

ECS will use three separate antennas to provide European coverage. Depending on the signal's destination, the transmitting earth station must send the bursts at different frequencies so that they pass through different repeaters and antennas. This is called 'frequency hopping' and is implemented by rapid changes in the oscillator frequencies applied to the frequency converters at the earth stations.

Because only five of the 12 ECS repeaters can be powered during solar eclipse, further use of this technique is made for an eclipse procedure which involves a rearrangement of the burst pattern prior to switching off some repeaters. Use can be made here of the fact that night traffic is substantially lower than that during the day. Tests to validate this eclipse procedure are included in the programme.

Prior to the TDMA system tests with OTS, the CEPT procedures have been used for tests with Symphonie and Intelsat. For this reason, and also because last year's OTS launch failure had a severe impact on equipment availability, tests with a transmission rate of 60 Mbit/s will not be repeated with OTS. After subsequent modification of the TDMA terminal, the tests will only be performed at 120 Mbit/s, which is destined to be the operational rate for ECS.

Channel Tests
A communications satellite system that forms part of the international network must conform to the international standards applicable to digital transmissions. This will be verified by well-established measurements, including tests of channel transfer characteristics (e.g. group delay versus frequency) and noise measurements. These standard tests must, however, be adapted to DSI operation

Figure 4 – The earth station at Bercenay-en-Othe, southeast of Paris, which will participate in the telecommunications tests.

and to satellite-link conditions. The latter are characterised by the fact that the BER changes if it rains. Thermal noise will therefore be injected in the signal path in order to study whether, for instance, the number of voice crackles per minute stays within the tolerable limits. DSI operation will be simulated by appropriate keying of the test signals.

Satellite Switching and Signalling Tests
An operational European communications satellite system cannot be used in isolation; it has to be integrated into, and form a part of the existing European telephone network. Tests will be conducted to investigate how far this can be accomplished without the introduction of too many special procedures for traffic via the satellite. The signal delay introduced by the distance between an earth station and a geostationary satellite, for example, is about

200 ms and this will create a problem for a signalling system designed for the very much smaller delays in the terrestrial network and which operates in a compelled mode, i.e. any digit of a called number is only transmitted after the receive side has notified good reception of the previous digit. Thus the satisfactory exchange of signals between the registers will have to be tested as well as those indicating congestion at the receiving end or the release of a circuit at the end of a call. Other tests will assess subscribers' reactions to the long propagation time with which most Europeans are unfamiliar, and to the presence of echo suppressors, which call for greater subscriber discipline in that speech at either end closes the incoming channel and a total blackout in conversation could result if the parties do not speak in strict rotation.

TELEVISION TESTS

ECS will provide two repeaters for the transmission of Eurovision signals. Consequently, the Orbital Test Programme will include tests to demonstrate that the service can meet the requirements of the European Broadcasting Union (EBU), a potential client for the future system, and EBU experts have in fact participated in the CEPT's definition of the test programme.

Digital transmission techniques do not yet play an important part in the television tests, since economics favour television transmission using a well-known frequency-modulation technique with analogue signals. As this has already been employed for many years and standard measurement procedures relying on automatic test equipment are well established, the OTP television test period is much shorter than the telephony test period.

Only a few of the tests in the telephony programme are directly related to assessment of subscriber reaction. In the television tests, however, physical measurements take second place to viewer reaction, primarily that to perceptible picture degradation.

Here again, the investigations concern transmission over a space segment path between earth stations. As the eye is more sensitive to distortion than the ear and a television receiver costs substantially more than a telephone, it is logical to allow still smaller signal impairments over this path compared with telephony transmission.

The television tests are directed primarily to four main areas of interest:

(i) Level measurements
Some Eurovision programmes are provided by different countries and would therefore be transmitted via different earth stations. The signal level should nevertheless remain steady since the eye is very sensitive to changes in the mean picture brightness. Mismatches between the terrestrial and satellite links have little effect on the signal level, but give rise to echoes, which can be a source of considerable irritation to the viewer.

(ii) Linear waveform distortions
These distortions, a typical effect of which is poor picture definition, will be studied by means of a sophisticated waveform signal composed of a pulse (representative of the fine structure of the picture) and a bar (to detect low-frequency distortions).

(iii) Nonlinear waveform distortions
Such distortion must be expected in a satellite link which includes two nonlinear output amplifiers. Typical effects are colour changes as a function of brightness.

(iv) Noise measurements
Random noise will probably be the most important single disturbance source here, and changes in its level will occur as meteorological conditions vary. The design criterion to be tested is that the signal-to-noise ratio should be better than 55 dB for 99% of the time.

PROPAGATION TESTS

The propagation experiment programme is extensive both in terms of the number of stations used (there will be about 35 throughout Europe) and in terms of experiment duration (two years). Differing substantially from the telephony and television tests, which call for frequent changes in configuration, the propagation experiments are characterised by the stability of configuration needed to study temporal and diurnal variations.

Propagation degradation occurs through attenuation (e.g. by rain), retransmission of the signal energy absorbed by the transmission medium as thermal noise, and rotation of the signal's plane of polarisation. Since these phenomena occur in both the uplink and downlink chains but not necessarily to the same degree, a special measurement configuration has been set up using two radiating beacons and a narrow-band on-board repeater. The beacons are earth-based and provide an earth/satellite/earth link; the repeater beacon provides a satellite/earth link. In this way effects on the downlink can be subtracted from the up + downlink to reveal the uplink effects.

The test schedule involves earth/satellite/earth transmissions from pairs of earth-based beacons (10 such pairs will be used). One beacon of each pair transmits on a polarisation consistent with signal reception, the other on the cross-polarisation at a level 15 dB higher. The satellite will relay the signal of the first beacon together with the depolarised component of the second. These two signals will be subject to the same degrees of gain or loss in the repeater, the downlink and the receiver, so that their ratio can be used to determine the uplink cross-polar isolation.

The satellite beacon will be used to measure fading in the downlink simply by recording this signal continuously on the receiver side together with the cross-polar isolation in this path. If at the same time the earth-based beacon signal is recorded, the uplink attenuation can be deduced.

DATA-TRANSMISSION TESTS

For use as a point-to-point data link, satellite communication has an important advantage over terrestrial links in that it is exposed mainly to thermal noise which gives rise to randomly distributed errors that can normally be readily corrected by appropriate coding. With a terrestrial link, however, impulsive noise usually dominates and this generates batch errors which can only be rectified by retransmission. A further advantage of the satellite is that the same signal can be received at many places simultaneously.

There is a wide choice of possible data-transmission experiments for OTS, examples being a broadband data link between high-energy physics laboratories in Switzerland, France, Germany and the United Kingdom, the computer-to-computer links between ESA establishments, remote printing of newspapers in Sweden, and the oil-platform links mentioned in the previous article. As yet, the general policy of the CEPT Administrations regarding data transmission is marked by their desire to study such new services carefully. Indeed, adequate use of frequency bandwidth and satellite power and proper use of the geostationary orbit are vital considerations (small stations have less pure antenna transmit characteristics). Any new service must satisfy a market need if it is to be economically viable and must take into account both the number of potential customers and the time periods during which the service would be of interest to them.

OUTLOOK

The fact that CEPT Administrations will perform extensive measurements over the next few years and have invested considerable amounts of money in the earth segment clearly demonstrates their interest in a European communications satellite system. Though the economics of a future ECS system may not yet be to the satisfaction of all administrations, and though integration of ECS into the existing network involves problems that depend on the levels of technology already available in the various countries, an operational ECS system could still be introduced in the early eighties. □

Technology Fallout from The OTS Programme

G. Blondin, Technology, Industry and Infrastructure Department, Directorate of Planning and Future Programmes, ESA
A. Dickinson, Satellite Systems Division, Communications Satellites Department, ESA

The European Communications Satellite Programme, initiated in the early 1970s, has included a Supporting Technology Programme (STP) within which to develop the critical units to be flown on ECS and thus to be tested on OTS. Development of these items was commenced by ESA in parallel with the early definition studies for ECS and OTS and was later integrated into the main OTS development contract. Some of the equipment developed under the STP has already been flown on the Canadian Communications Technology Satellite (CTS) launched in January 1976.

The criterion used for inclusion of equipment items in the Supporting Technology Programme was that they should be critical in terms of either schedule and/or technological difficulty. On this basis, the following were selected for support:

- Travelling-wave-tube amplifiers
- Dual polarised reflector antennas
- Repeater hardware, including parametric amplifiers, receivers and filters
- Mechanisms
- Structures
- Infrared earth sensors
- Momentum wheels
- Reaction control equipment
- Thermal control equipment (including heat pipes)
- Solar arrays
- Power-conditioning and battery-control equipment.

TECHNOLOGY ACTIVITIES

Travelling-Wave-Tube Amplifiers (TWTA)

It was decided early in the ECS programme, for frequency co-ordination reasons, that the operating frequencies for the uplink from ground to satellite and for the downlink from satellite to ground, should be approximately 14 and 11 GHz, respectively.

This change in frequency from the 4/6 GHz used on earlier communications satellites necessitated significant payload-equipment development, including the provision of a high-efficiency TWTA with an output of some 20 W. In January 1971, therefore, two parallel contracts were awarded for its development. In 1972, the TWT developed by Thomson-CSF (France) was selected for a complete programme of qualification and life-testing, but activity on the second TWT at AEG-Telefunken

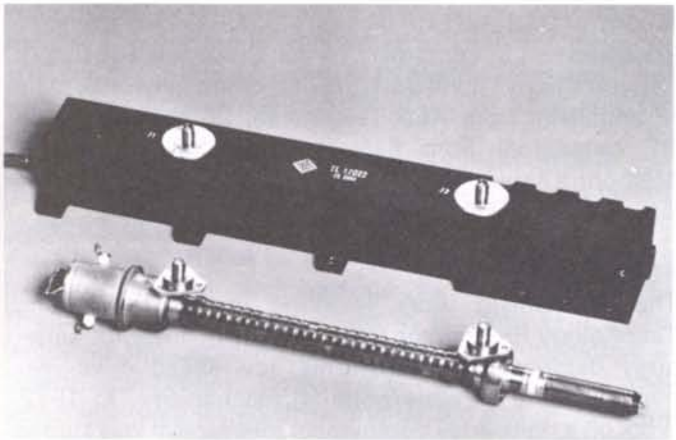

Figure 1a – Travelling-wave tube developed by AEG, Germany.

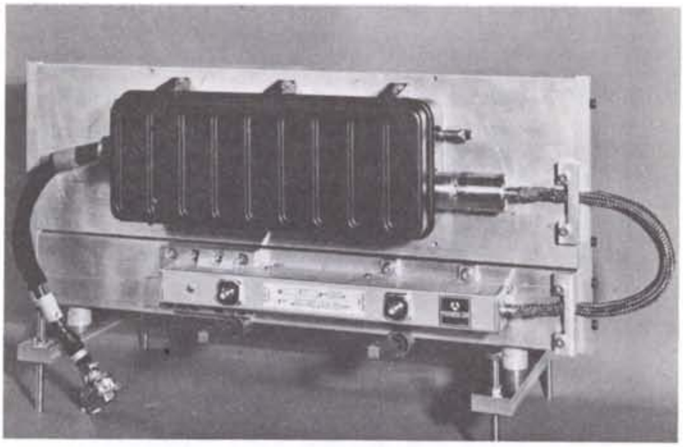

Figure 1b – Travelling-wave-tube amplifier developed by Thomson-CSF, France and CGE-FIAR, Italy.

(Germany) was also continued. Development of the electronic power conditioner for both tubes was entrusted to FIAR (Italy).

In addition to the single-collector tubes on which development had initially commenced, work was also started on improved high-efficiency versions of both TWTs using multiple collectors, the aim being to achieve an overall TWT efficiency greater than 40%. The single-collector tubes (efficiency 32%) were qualified and life-tested and have now been proven in orbit on CTS. The multicollector tubes which have in fact achieved an efficiency of about 42% have also been qualified and are undergoing life-testing. Four Thomson-CSF and four AEG-Telefunken multicollector tubes will be flown on OTS (Fig. 1).

Dual-Polarised Reflector Antennas
To permit ECS to use the same frequency band twice and thus increase system capacity, signals will be transmitted and received on two orthogonal polarisations. This has required the development of antennas with a high degree of polarisation purity.

After extensive studies of the various options, front-fed antenna configurations were selected, the elliptical beams required for complete European coverage being achieved with circular, distorted-profile, parabolic reflectors. A competitive development phase was followed in 1973 by the award to Selenia of contracts to develop and qualify three antennas, representative of the types required for OTS (Fig. 2).

In parallel, various theoretical and breadboard activities have been undertaken on alternative techniques and technologies. These have included: (i) a theoretical investigation of wave propagation in a corrugated horn with an elliptical cross-section, performed by Eindhoven University of Technology; (ii) a preliminary investigation by Marconi Space and Defence Systems (UK) of the use of offset-fed reflectors with dual circular polarisation; (iii) development, by TERMA (Denmark), of a reflector with polarisation cleaning properties; and (iv) a study programme on pattern prediction at higher frequencies for low- and medium-gain antennas, performed by the Technical University of Denmark and TICRA (Denmark).

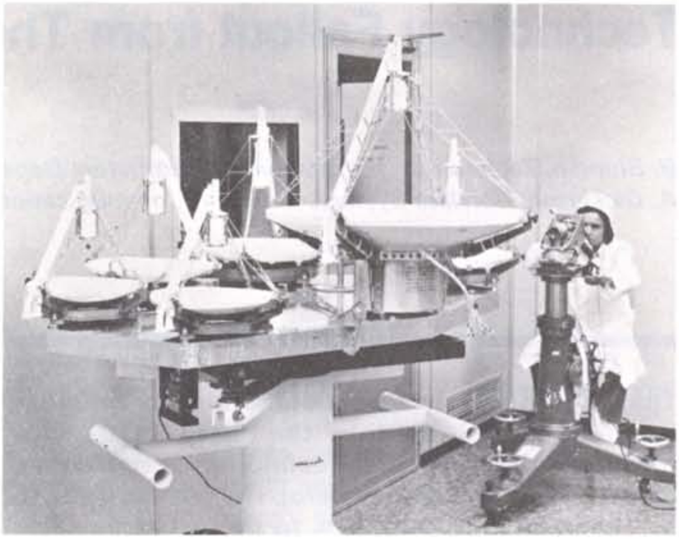

Figure 2 – Qualification models of the first dual-polarised antennas developed for OTS by Selenia, Italy.

In addition to this work on SHF antennas, a computer program was developed by TICRA for determining the radiation patterns of VHF antennas. This program has been used by both industry and ESTEC in the design and analysis of the VHF antenna systems for OTS and Meteosat.

Repeater Hardware
In February 1971, two parallel contracts for the definition of a modular repeater were placed with consortia led by AEG-Telefunken and Siemens (Germany). Breadboards of all units had been developed by the end of 1972, at which time the AEG-Telefunken team was chosen to proceed with development and qualification.

Incorporated in the modular-repeater activity were low-noise parametric amplifiers, developed by GTE (Italy), using an evanescent-mode waveguide circulator and a solid-state 40 GHz pump. Other repeater units developed for use on OTS and ECS include input filters and a beacon generator by LM Ericsson (Sweden), receivers and output networks from Thomson-CSF, branching networks, main IF amplifiers from AEG-Telefunken, up-converters and RF calculators from Selenia (Italy), IF filters from Marconi, a carrier supply from FIAR, and a repeater power supply from ETCA (Belgium).

Mechanisms
The mechanism work included in the Supporting Technology Programme fell into three main fields: solar-array deployment mechanisms, low-speed drive mechanisms and antenna-pointing mechanisms. In 1972, work on a rigid-array deployment mechanism was started and progressed very satisfactorily at MBB (Germany). The array was fully tested the following year and was subsequently chosen for OTS.

Figure 3 – View of the European Space Tribology Laboratory at Risley, UK

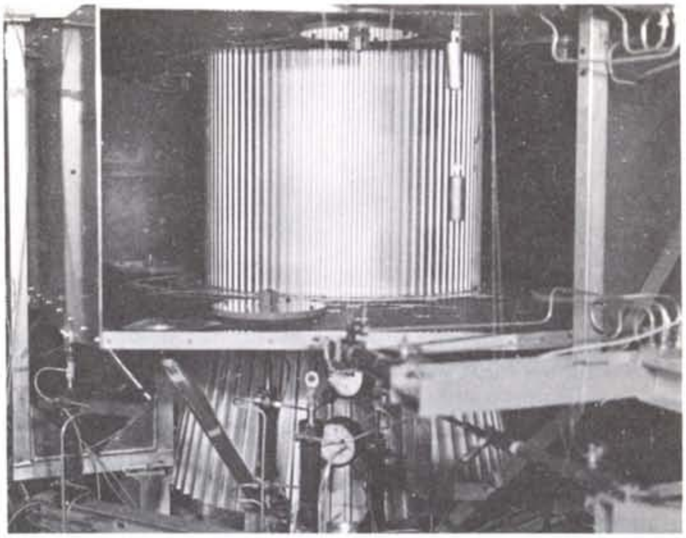

Figure 4 – Structural Mass Optimisation Programme in progress at Contraves, Switzerland.

In the field of solar-array drive mechanisms, i.e. bearing and power-transfer assemblies or BAPTAs, two different designs for rotating solar panels at one revolution per day were built by Marconi and Hawker Siddeley Dynamics (UK). These embodied dry (lead) lubrication for the bearings, dry (MOS_2) lubrication for the slip rings, and direct-drive (gearless) motors. As a result of this and other work, lead lubrication was chosen for the BAPTAs on OTS. Both mechanisms were successfully subjected to qualification tests under thermal-vacuum conditions in 1973 and, as an extrapolation of these designs, flight units have been developed and qualified for OTS.

An antenna-pointing mechanism (APM) is needed to adjust the direction of an antenna on a communications satellite to compensate for spacecraft movements either during the launch phase or during space operations, and to allow a flexibility in the ground areas served. A contract was placed with Marconi in 1973 to develop such a device. The first model was tested in 1974 and development of the unit has continued to qualification, but it has subsequently been decided not to use an APM on OTS.

An essential element of the development of any mechanism for space application is an adequate test facility in which to examine the considerable tribological problems involved. It was for this reason that ESA decided to construct, equip and operate its European Space Tribology Laboratory at Risley in England (Fig. 3) for studying the problems associated with lubrication in space applications. Both the BAPTA and APM mechanisms were tested there and by the end of 1975 the laboratory was ready to receive the OTS flight-model solar-array drives for qualification, acceptance and life-testing.

Structures

Because of the great need for lightness in satellite structures, a contract was let to Contraves (Switzerland) early in 1973 for a Structural Mass Optimisation Programme (SMOP), concentrated on the development of a minimum-mass primary structure (Fig. 4) for an ECS configuration. The resulting design includes a corrugated cone and cylinder structure with carbon-fibre-faced honeycomb platforms. A static test on the structure completed in 1974 showed good correlation between analysis and test and the work was continued to completion, with dynamic (sine-vibration) and modal-survey tests.

Infrared Earth Sensors

The requirements for ECS, identified by studies of the operational system undertaken in 1971, dictated a very precise attitude and orbit control pointing accuracy, using a two-axis infrared earth sensor to provide attitude signals. This was beyond the state-of-the-art for sensors available at that time in Europe and two parallel preliminary design study contracts were therefore awarded, in 1971, to SODERN (France) and Officine Galileo (Italy) for detailed definition of the characteristics of such a sensor. SODERN investigated sensors based on the use of thermovoltaic detectors (e.g. thermopiles), which do not require modulation of the earth-emitted IR radiation incident on the sensor, while Officine Galileo studied sensors based on the use of non-thermovoltaic detectors (e.g. bolometers). A contract for the development of the latter type of sensor was placed with Officine Galileo late in 1972. Manufacture of a qualification model was completed in 1974, and the device was incorporated into the OTS engineering model in 1975. The SODERN sensor has also been selected for flight on OTS.

Momentum Wheels
It was originally thought that the baseline attitude-control and stabilisation system for OTS and ECS would consist of a momentum wheel mounted in a double-gimbal system, together with associated attitude sensors and momentum unloading systems. The new wheel and its implications for the attitude control system for the flexible solar arrays called for an in-depth study of a number of attitude control laws. Contracts were placed with MATRA (France) and MBB for detailed comparative investigations of different types of wheel-control systems and the selection of a preferred concept.

A contract was placed with Teldix (Germany) for the development of a double-gimballed momentum wheel (DGMW) based upon that developed for and flown on the Franco-German Symphonie spacecraft. The engineering model was qualification tested and the manufacture of flight-standard models was approved late in 1973. Qualification testing of these models began in 1974 and development of a new type of gimbal actuator (stepper motor) was started late in that year and completed by the end of 1976.

An ESA contract was also placed with Philips in 1972 for the development of a 30 Nms flywheel (Fig. 5) using a grease journal bearing. The basic concept was later substantially improved by redesign and the definition of improved manufacturing processes so as to minimise grease losses during environmental testing and vacuum operations. The soundness of this technology was recognised with the selection of this wheel as one of the two to be carried on OTS. A Teldix fixed momentum wheel derived from the DGMW contract is also used.

For a number of applications, a wheel with only one gimbal can be used in a high-accuracy control system, at the expense, in some cases, of increased fuel consumption and increased thruster utilisation. This allows the double-gimballed momentum wheel to be used as a single-gimballed momentum-wheel controller in the event of a failure, thus considerably improving the reliability of the overall system. Contracts were awarded in 1974 to British Aircraft Corporation for the study of single-gimballed momentum-wheel back-up mode controllers for double-gimballed momentum wheels and to Teldix for construction and testing of a single-gimballed wheel.

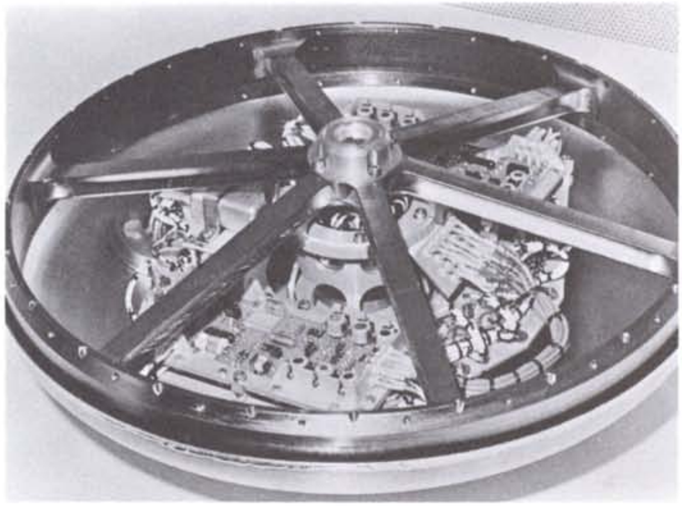

Figure 5 – Grease-bearing flywheel developed by Philips, The Netherlands.

Reaction Control Equipment
A reaction control system using hydrazine as fuel was selected as the baseline for the attitude and orbit control of OTS. Contracts were thus awarded as part of the OTS Supporting Technology Programme to SEP (France) for the development and qualification of a zero-gravity hydrazine expulsion tank relying on the completely passive use of hydrazine surface-tension forces, and to develop and test a catalytically-decomposed-hydrazine thruster.

In addition, to examine the possibilities of significant mass savings, four contracts were placed in 1972 with MBB, HSD, LAAS (France), and SEP to study the application of electric propulsion to the north-south orbital control of geostationary applications satellites and to review the state-of-the-art of European technology.

Thermal Control
Communications satellites involve on-board dissipation of considerable amounts of electrical energy, originating principally from the DC to RF conversion process within the communications packages. Not only is the amount of heat involved high, but it varies both with duty cycle and with spacecraft illumination conditions. A concentrated development effort on active means of thermal control was therefore necessary in this area if the ECS programme was not to be subject to delay and uncertainty.

Early in 1972 two parallel contracts were placed with MBB-IKE (Germany) and IRDC (UK) to develop a small-diameter heat pipe for application in the ECS travelling-wave-tube radiator. Emphasis was placed on achieving a flexible, high-reliability pipe suitable for use in the construction of panels for electronic equipment mountings. MBB succeeded in developing a multi-artery ammonia–stainless steel mesh–aluminium pipe which transports 15 W with less than 6°C temperature drop over the range 0° to 80°C, while IRDC produced a multi-artery acetone–stainless steel mesh–aluminium unit.

The 'Institut für Kernenergetik' (IKE) subsequently demonstrated the long-life capability of the ammonia–stainless steel–aluminium combination. An investigation into corrosion effects in aluminium and acetone heat pipes was conducted by IRDC and the useful manufacturing information gathered will be used in future designs.

Another contract awarded in 1972 was to HSD for a design study of radiator plates for use with high-dissipating components on board a communications satellite. The study included a comparison of solid-profiled and heat-pipe radiators for the ECS satellite configuration, it being concluded that the latter was more efficient above a particular dissipation level threshold. A preliminary design was produced which optimised the heat-pipe configuration, although the successful developments in TWT efficiency, with consequent reduced dissipation, have now made heat-pipe radiators unnecessary for the tubes on ECS.

A software system for the rapid evaluation of thermal-test data was developed by SEMA (France), initially to be utilised during the OTS thermal-model tests, but it is also of value for other satellite projects.

Continued work during the following years on the life-testing of heat pipes showed great promise for the steel mesh–steel tube combination. A number of new activities, all in direct support to OTS, but also applicable to ECS, were also started and were completed in 1976:

- degradation testing of thermal surfaces in the space environment; two series of tests were conducted at DERTS, Toulouse
- electrostatic-discharge testing of various surfaces under electron bombardment, also conducted at DERTS
- electrostatic-discharge testing of a large sample of thermal blanket (representing the VHF antenna ground plate of OTS), conducted at DFVLR, Porz-Wahn.

Energy Conversion

Communications satellites of the ECS type require a primary electrical power supply of about a kilowatt. Analysis of various techniques for supplying primary power indicated that silicon solar cells remain the most attractive source. For three-axis-stabilised satellites, the cells are mounted on orientable panels and provide approximately 1 kW per 10 m^2 of array area. An energy-storage system is required for eclipse periods and hermetically-sealed NiCd batteries are considered the best choice for spacecraft with lifetimes of 5-10 years. Stable and reliable power transfer between the solar-cell array, battery and spacecraft loads is accomplished by the power-conditioning and control system.

Because of budgetary and time-scale constraints, efforts on power systems within the Supporting Technology Programme were concentrated on supplementing activities already under way, and in particular on filling gaps in inadequately covered areas.

Based on a solar-array design study conducted in 1971, MBB developed and manufactured three 2.2 m^2 lightweight rigid panels, each with a specific mass of 26 kg/kW, excluding stowage and deployment mechanisms. The panels embody an aluminium-honeycomb core with filament-wound carbon-fibre-reinforced face sheets and frames. The system was tested extensively and successfully in 1972 and both its basic design concept and technology have been incorporated in the flight arrays for OTS.

As part of the STP, a folding, flexible solar-cell blanket was designed and developed at AEG-Telefunken for the Canadian CTS satellite. The blanket was integrated with a stowage and deployment assembly manufactured by SPAR of Canada. Development was successfully completed with a very extensive qualification test programme and manufacture of the final flight unit was completed on schedule at the end of 1974. The unit has been operating successfully in space on CTS since early 1976.

To ensure that the performance and reliability of the battery system would be adequate for 5-10 year space missions, additional effort was needed to supplement work being conducted under ESA or national programmes.

A contract was placed in 1972 with Van der Heem

(Netherlands), with Hawker Siddeley as subcontractor, for the development of a battery control, protection and monitoring unit. A breadboard model was produced which monitors individual cell voltages, protects the battery against polarity reversals or failure of individual cells, and adjusts battery recharge automatically on the basis of previous discharges or on telecommand from the ground.

An electromechanical high-power relay adapted to the 50 V distribution of OTS was developed by AEM (France). All evaluation tests were successfully completed and the qualification phase started as scheduled by the end of 1973. The device was fully qualified in 1974 and incorporated into OTS, and it will also be used on ECS.

Finally, in a follow-up to a 1971 contract, ETCA (Belgium) was engaged on the definition of a digital shunt regulator. A breadboard test confirmed its low output impedance and exceptional transient response.

APPLICATIONS ON OTS AND CTS

As has already been mentioned, various technology items developed for OTS and ECS have already been flown on CTS, namely a 20 W, 12 GHz TWTA and a parametric amplifier as part of the payload, and the folding, flexible solar-cell blanket.

OTS relies heavily on the developments of the Supporting Technology Programme. Its antennas and repeater are derived directly from the antennas developed by Selenia and the repeater hardware described above and much of the platform equipment is also the direct outcome of STP activities, including:

- the lightweight carbon-fibre rigid-panel arrays from MBB
- the BAPTAs from HSD
- the infrared sensor from Officine Galileo
- the fixed momentum wheel from Teldix
- the power relays from AEM
- and the digital-shunt and battery-control concepts.

Figure 6 – OTS infrared earth sensor, from Officine Galileo, Italy.

FUTURE APPLICATIONS

Most of the technology developed within the STP and being used on OTS has been developed with ECS in mind. However, to take advantage of the improved techniques and technologies that have become feasible since the commencement of the STP and also to increase the flexibility of the equipment to meet future commercial needs, some new developments are being undertaken, mainly in the areas of power, telemetry, tracking and command subsystems, building where applicable upon STP experience.

The STP should thus have provided a solid base for ECS and other communications missions of the early 1980s. Later missions, such as more advanced communications and television-broadcast satellites, will, however, demand increased capabilities and thus improvements in components, units and payload configurations in order to use available power, payload mass and frequency allocations more efficiently. A number of these items can be considered part of the technology fallout from the OTS/ECS Supporting Technology Programme.

This is the case, for instance, in respect of payload configurations, where some work has already been done on replacing the heavy IF filters working in the 1 GHz range by advanced carbon-fibre waveguide filters with similar performance and about one third of the mass. The work on reflector antennas, especially the feed systems for high polarisation purity, on technology for mechanical stability in lightweight structures, and on reflector

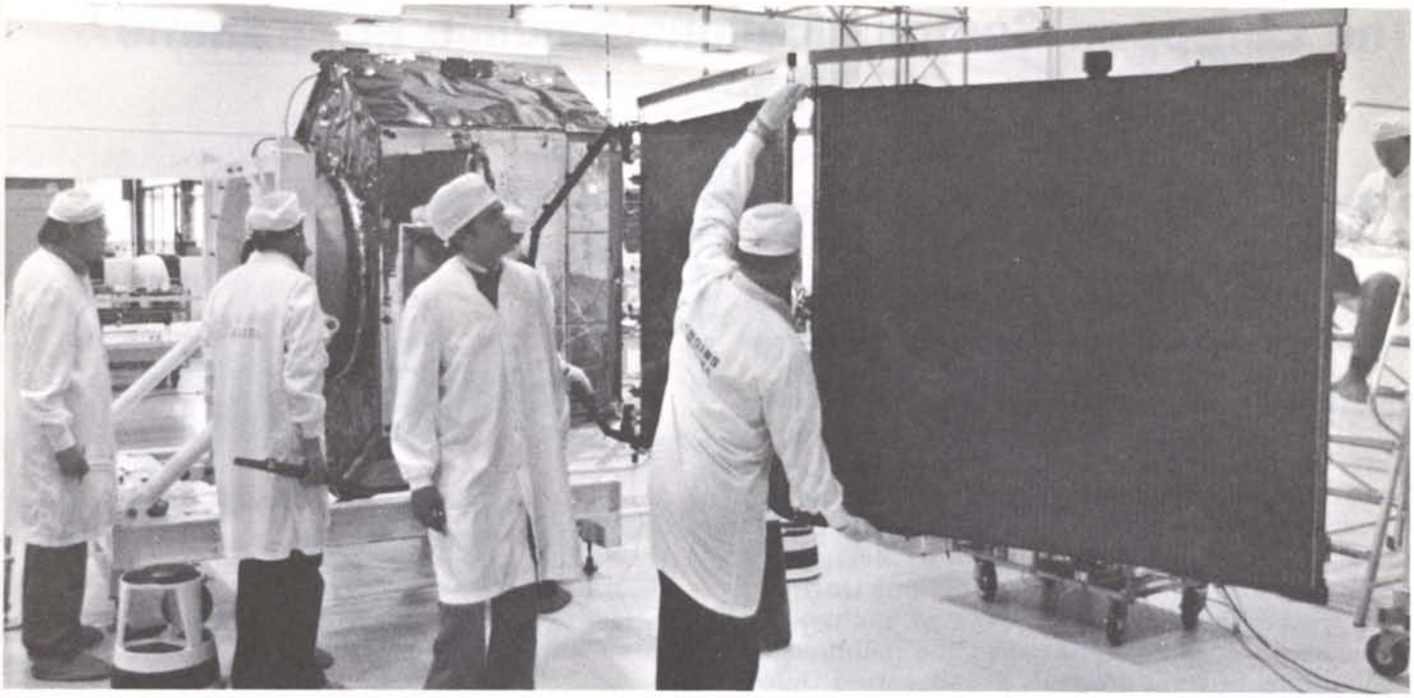

Figure 7 – Carbon-fibre rigid-panel arrays developed by MBB, Germany.

geometry, as well as the software for pattern prediction, will certainly prove useful for future developments in this area. Furthermore, present OTS tube technology is capable of extension; for a millimetre-wave (20 GHz) communications mission, for example, a medium-power TWTA will be needed, probably in the 10 W to 20 W region, and this work would be a follow-on from the present OTS tubes.

With the advent of a television-broadcast mission, the generation and handling of several kilowatts of on-board power will become necessary, leading to a number of technology activities that have already been started and have involved developments within the Supporting Technology Programme; for example

- the continued development of multi-kilowatt arrays, including flexible, hybrid and ultra-lightweight rigid arrays
- the continued development and application of more efficient solar cells
- the development and qualification of thin-walled battery cells and improved battery packaging
- the development of improved power electronics, with emphasis on sequential switching, shunt regulation and battery-discharge regulation
- application of hybrid thick-film technology.

In the field of attitude and orbit control, a number of STP activities will prove valuable for high-accuracy and long-life-reliability requirements in future applications, including:

- qualification of surface-tension tanks
- development of single-gimballed momentum wheels with self-locking actuators and DGMWs.

Studies on future communications spacecraft have shown that heat-pipes will very probably be required for cooling TWT radiators. A further problem anticipated with an advanced ECS is the thermal conditioning of the batteries needed to provide the estimated 1 kW needed in solar eclipse. New techniques, including the use of metal-hydrogen combinations, are being investigated in an attempt to reduce battery mass, but there is little reason to believe that they will be much more tolerant in terms of operating temperature extremes. The work performed since 1970, partly under the OTS Supporting Technology Programme, on artery heat pipes, represents a considerable effort and is unquestionably a milestone in this area of technology.

CONCLUSION

The activities that have been described will certainly contribute substantially to the build-up of an advanced European technology programme, involving both payload and spacecraft support technology, the results of which can be incorporated in due course in the second generation of European communications satellites and other new communications missions. Thus, in addition to meeting its primary objective of technology support to OTS and ECS, the STP should provide a firm basis for the developments needed to meet the technology requirements of the advanced missions of the 1980s. □

The European Communications Satellite Programme

P. Bartholomé, Communications Systems Division, Communications Satellites Department, ESA

The future European Communications Satellite (ECS) system is scheduled to start operating in 1981. It will be used by the Post and Telecommunications Administration members of the CEPT* to complement the existing public terrestrial network. In addition to carrying a portion of the intra-European telephone traffic, it will provide an improved means of exchanging television programmes between the member organisations of the European Broadcasting Union (EBU). The system will be owned and managed by EUTELSAT, an organisation set up by the P&T Administrations. It is foreseen that ESA will supply, launch and maintain in orbit the satellites required by EUTELSAT, while individual Administrations will be responsible for the construction and operation of their respective earth stations.

THE MISSION OF THE ECS SYSTEM

To establish an envelope for the volume of telephone traffic to be routed by satellite, the CEPT has assumed that the ECS system would be used for long-distance links and that it would have to cope with only a fraction of the forecast total volume of traffic for these links. On the basis of this assumption, the number of telephone circuits which will be routed by satellite in 1985 will be of the order of 10 000.

For television, the requirements are for the permanent availability of transmission links for two independent programmes, with the possibility to transmit more programmes occasionally, given a certain period of notice. It is important to note that, in the EBU specifications, the transmission of a television programme implies the transmission of a package consisting of a video signal, a high-quality international sound signal, and up to twenty commentary channels in various languages. Furthermore, and independently of the programme package, it is required to route a number of so-called 'service channels' intended for network control via the satellite.

* CEPT: Conférence Européenne des Administrations des Postes et Télécommunications.

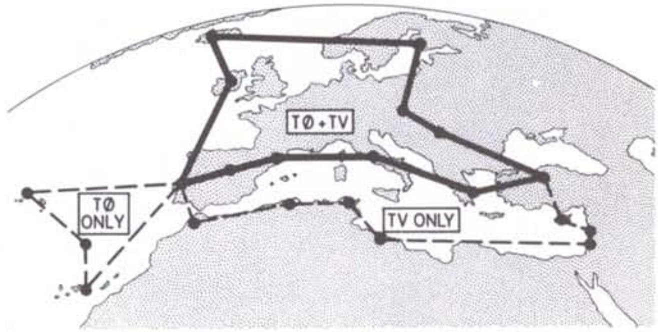

Figure 1 – Telephony and television coverage zones.

An important feature of the traffic is the geographical distribution of the various stations in the network and their relative importance in terms of transmission capacity. Figure 1 shows a projection of the Earth as seen from a geostationary satellite stationed at 10° east longitude. It also shows the areas where telephony and television services are required. These areas do not overlap completely. Unlike telephony, the television service does not extend to the Atlantic Islands, but does include most of North Africa as well as part of the Middle East.

The type of traffic in the two areas is naturally somewhat different. Telephony is essentially point-to-point, with a high concentration of sources in central Europe. The area can be conveniently divided into three regions, as shown in Figure 2, each being illuminated by a high-gain 'Spot-beam' antenna on the satellite. Television tends to have more of a multi-destination nature and requires the use of a wider 'Eurobeam' for most transmissions.

PRINCIPAL CONSTRAINTS ON THE DESIGN OF THE ECS SYSTEM

A communications satellite system consists of four basic elements: a space segment, an earth segment, the

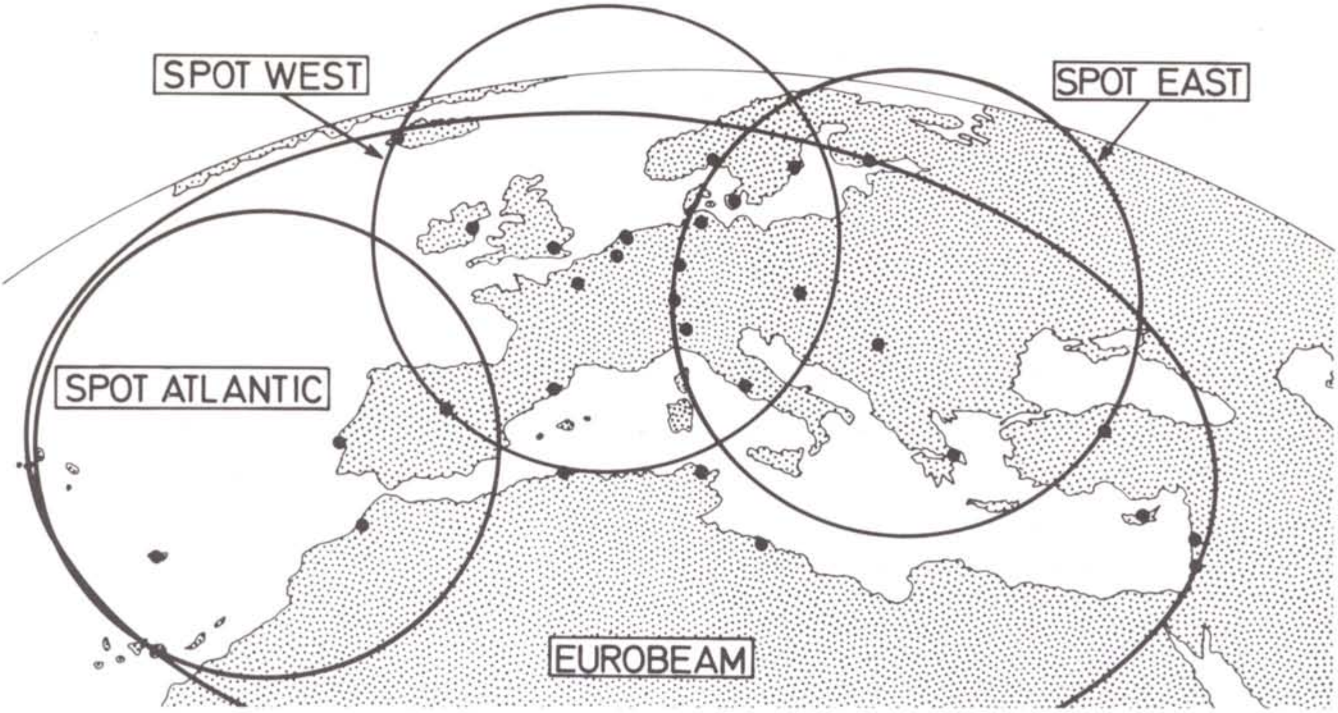

Figure 2 – Probable antenna patterns for the European Communications Satellite.

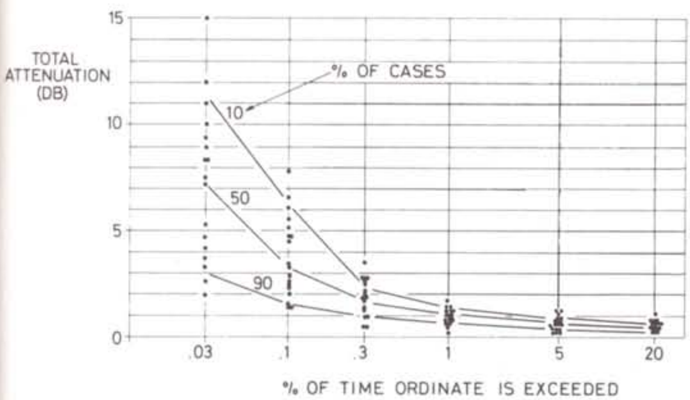

Figure 3 – Total attenuation at 11.4 GHz during worst month of calendar year.

propagation medium through which they are interconnected, and the frequency spectrum in which the system operates. All four are characterised by specific limitations which impose certain constraints on the design of the overall system.

FREQUENCY SPECTRUM

In view of the insurmountable problems of interference with a comprehensive terrestrial radio-relay network and with other satellite systems which would be encountered in Europe if one wanted to implement a regional system at 4 and 6 GHz, it was decided right from the outset to opt for frequencies above 10 GHz. From the bands between 10 and 15 GHz available for the fixed satellite service in Europe (Region 1), the CEPT chose the following for the future ECS system:

Uplinks	14.0 – 14.50	(500 MHz)
Downlinks	10.95 – 11.20	(250 MHz)
	11.45 – 11.70	(250 MHz)

There is a maximum of 500 MHz available. Given the volume of traffic to be accommodated, this constitutes an important constraint on the design of the system, which will be severely band-limited. Spectrum re-use is therefore essential.

A second important constraint arises from international regulations, which impose a maximum limit in these frequency bands on the flux of radio-frequency (RF) power created at the Earth's surface by a satellite. This has implications for satellite design, since the RF power radiated in each frequency channel must remain below a ceiling which is a function of the bandwidth of this channel, the radiation pattern of the associated antenna, the type of signal transmitted, and the kind of modulation used. Conversely, the power-flux limitation at the Earth's surface sets a lower limit to the sensitivity of the receiving systems and hence to the size of antenna reflectors.

THE PROPAGATION MEDIUM

At frequencies above 10 GHz, the attenuation suffered by radio signals traversing the atmosphere can be significant, and suitable allowances must be made in the link budgets. Since the attenuation is a time-varying phenomenon which can only be described in statistical terms, the magnitude of the link margins is a function of the grade of service required from the system; it is also dependent on the weather conditions prevailing at the location of the earth station which forms part of the network.

Atmospheric attenuation occurring at one station affects signals received from others, as well as signals sent to other stations. The occurrence of attenuation at any point in the network is therefore of concern to all participants, since it is assumed that all stations must be able to communicate with each other. It follows that the system design should take account of any systematic difference between attenuation statistics in the different regions to be covered.

There is, however, no clear evidence that such differences exist and, in the interests of simplicity and standardisation, ESA has adopted for the design of the ECS system a theoretical model based on experimental data collected in Europe over several years.

Figure 3 illustrates the statistical distribution of attenuation for an average downlink frequency (11.4 GHz). The model used for ECS is the curve corresponding to 50% of cases, i.e. giving the attenuation exceeded during the worst month of an average year. At 14 GHz, the attenuation has been shown to be about 1.5 times as high as at 11 GHz (expressed in dB).

To evaluate the constraint introduced by the propagation medium on the design of the system, one must first relate the attenuation model to the quality criteria specified for the two types of services, telephony and television. These are summarised in Tables 1 and 2, respectively.

In the case of telephony, these criteria are expressed in terms of three levels of bit error rate which must not be exceeded for certain time percentages. For television, two levels of quality are specified, one 'very high' for at least 99% of the time, and the other 'usable' for 99.9% or more of the time.

It is, of course, not immediately obvious which of these criteria is the hardest to meet, since complete link budgets must first be established and this presupposes that all parameters of the system are known. In the ECS system as currently defined, it appears that the design is dictated by

TABLE 1

Transmission Quality Required for Digital Telephony

Bit Error Rate	Availability
< 1 in 10^6	80% of worst month
< 1 in 10^4	99.7% of worst month
< 1 in 10^3	99.99% of any year

TABLE 2

Transmission Quality Required for Analogue Television

Quality Criterion	Availability
Luminance $S/N \geq 55$ dB International sound $S/N \geq 56$ dB Commentary $S/N \geq 29$ dB	99% of worst month
Service continuity	99.9% of worst month

the quality criterion applicable to telephony in clear-weather conditions and that if this criterion is met all others are automatically satisfied. The constraint introduced by the propagation medium therefore vanishes theoretically as far as attenuation is concerned. However, this presupposes that the propagation model selected adequately reflects reality, and this has yet to be confirmed by further experiments. Moreover, the problem must be seen in statistical terms, since the weather is a random process which varies widely from year to year, with wide deviations about any average value.

Another possible limitation introduced by the propagation medium arises in connection with the possibility of re-using the frequency spectrum by employing polarisation discrimination techniques. The principle of such techniques is to transmit two different signals in the same frequency channel, but with orthogonal polarisations (either linear and at right angles in space, or circular and with opposite senses of rotation). The degree of isolation that can be achieved between the two signals at the level of the individual elements that constitute a transmission chain, i.e. antennas, waveguides, orthomode transducers, etc. is usually adequate, but the overall isolation of the chain as a whole must be expected to be lower, and one source of degradation is the propagation medium. The importance of this factor has been investigated experimentally and it can be said that, although the influence of atmospheric effects on polarisation discrimination is not negligible, propagation will not introduce a significant degradation factor.

THE SPACE SEGMENT

The main constraint that weighs on the design of the space segment is that the mass and size of the satellites must be compatible with the launchers used to place them in orbit. For the European system, the choice was between NASA's Delta-3914 which is capable of placing a 450 kg satellite such as OTS into geostationary orbit, and Europe's Ariane launcher which is currently under development and which offers roughly twice this capacity. It is, of course, important to remember that in order to maintain a service corresponding to the mission assigned to the system, in spite of inevitable failures of all kinds, probability theory predicts that several launches are necessary to span a period of ten years, the exact number depending on many parameters which include the capacity of the satellite, its design lifetime and reliability, and the degree of confidence one attaches to the success of the mission. The impact of the choice of satellite on the cost of launches, and hence on the cost of the whole system, is therefore significant.

THE EARTH SEGMENT

The earth segment of the ECS system will consist eventually of some 30 stations. So far, one station per country has been envisaged, except for a few cases in which there would be two. With so many stations, the cost of the earth segment will obviously be an important fraction of the total cost, and care must be taken to achieve the right balance between space and earth segment costs. Since each user Administration will bear the full cost of its own terminal, in addition to paying a share of the space-segment cost (related in some way to the use made of it), emphasis must be placed on minimising the cost of individual stations in order to make the system economically attractive. Furthermore, the installation of earth stations requires an unavoidable investment at the outset, whereas the expenses related to the space segment are staggered in time and have an associated probability factor so that there is always a possibility that some of the space-segment expense foreseen will not be incurred.

The main constraint with regard to the earth segment is therefore to avoid the use of equipment, technology and techniques which bear heavily on the cost. In concrete terms, this has the following implications. The antenna reflector should not be more than 15 to 20 m in diameter; beyond this, the cost is likely to increase steeply, particularly if stringent requirements are put on the polarisation characteristics in connection with frequency-spectrum re-use. The peak power of transmitters should be compatible with the use of air-cooling techniques, which sets a ceiling of about 2 kW. Low-noise receivers should preferably be uncooled for easy maintenance. The number of transmitting and receiving chains should be minimised and equipment should be standardised.

Special mention should be made in this respect of the stations that will be used by the EBU in countries not included in the CEPT area. It is not envisaged that these stations will be used for any purpose other than transmitting and receiving television programmes, and it is particularly important to keep their costs within acceptable limits for potential users.

MAIN CHARACTERISTICS OF THE SYSTEM

TRANSMISSION TECHNIQUES

A comparative study of transmission techniques was made to determine ways of accommodating the maximum number of telephone conversations per unit of bandwidth. The solution which came out best is four-phase PSK/TDM* digital transmission with multiple accessing of stations in time sequence (TDMA)*. In addition, Digital Speech Interpolation (DSI) techniques will be introduced to maximise efficiency in the use of satellite channel time.

A similar study was carried out to determine the best transmission techniques for television programmes. The conclusion was that, although in principle the same digital techniques proposed for telephony are applicable, considerable development effort would be required to introduce a digital television system satisfying EBU

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* PSK = Phase-Shift Keying; TDM = Time-Division Multiplex; TDMA = Time-Division Multiple Access.

requirements by 1981. Such an effort did not seem justified in the context of the potential advantages of this approach and it has been decided to retain the well-established FM technique at least for the first few years.

FREQUENCY RE-USE

In the European context, and with present-day technology, there is no scope for extensive spectrum re-use by means of multiple nonoverlapping antenna beams. Polarisation-discrimination techniques are therefore the obvious choice, provided sufficient isolation can be maintained between the two signals transmitted in the same frequency channel with two orthogonal polarisations. This is expected to be the case in clear-weather conditions. As already stated, atmospheric effects have been shown to cause perceivable degradation in polarisation discrimination, but cases in which the isolation will drop below acceptable levels will be fairly rare and, as a time percentage, will be of the same order as outages due to equipment failures. It has therefore been decided to implement 100% frequency re-use by polarisation discrimination in all satellite antenna beams. Although there is still insuffcient information to state a definite preference for either linear or circular polarisation in this respect, the fact that better performance can be obtained from linearly polarised antennas with the present state of the art has dictated the choice for ECS.

THE SATELLITE CONCEPT

The original concept of an ECS satellite as defined in 1971 was a large three-axis stabilised spacecraft, weighing about 750 kg, to be launched by an Atlas-Centaur or a Europa-III vehicle. It was assumed to carry twelve fully redundant repeater chains, giving 1000 MHz of transmission bandwidth with complete frequency re-use by polarisation discrimination. There were two types of repeater chains: six with a nominal bandwidth of 120 MHz associated with a Spotbeam antenna on the transmit side, and six with a bandwidth of 40 MHz associated with a Eurobeam antenna. The intention was to use the first group, providing three quarters of the total capacity, for transmission involving only stations located in the central area, while the second would be assigned to transmission involving peripheral stations. In the interests of simplicity and flexibility of operation, receiving antennas were all of the Eurobeam type, so that all stations could have access to all repeater chains. This concept served as a basis for the design of OTS, which has two 40 MHz chains associated with a Eurobeam antenna and two 120 MHz chains associated with a Spotbeam.

Subsequently, however, the wish to standardise earth-station TDMA equipment to a single transmission rate of 120 Mbit/s made the concept of a uniform channel bandwidth prevail. The plans for ECS are therefore to fill the 1000 MHz available with 12 chains of 80 MHz, all equipped with 20 W TWTAs (Travelling-Wave-Tube Amplifiers). With this arrangement, it is no longer possible to provide telephone service via the Eurobeam transmit antenna of the satellite, since the power radiated in the direction of the peripheral stations would be insufficient. The solution is to cover the telephony area with three overlapping Spotbeams, as shown in Figure 2. A Eurobeam can of course still be used for television provided that the signal bandwidth remains within 40 MHz.

As work on the development of OTS proceeded, the idea of using the same basic spacecraft for the first generation of ECS became more and more attractive, particularly after the decision was made to change the type of launcher and to switch from a Delta-2914 to a Delta-3914. This gave OTS significantly more growth potential and indeed made it possible to propose it as a basis for a new concept for ECS, albeit at the cost of a few sacrifices in the operational mission. More recently, the decision has also been taken to use Ariane launchers for ECS since these will be available operationally from 1981. Although the capacity of these new launchers will be considerably larger than that of the Delta-3914s, it is not intended to modify the now accepted ECS design, but rather to consider the possibility of launching a 'passenger' spacecraft with ECS.

THE SPACECRAFT

The main difference between the OTS and ECS concepts will be in the Attitude and Orbit Control System (AOCS). For OTS, whose orbital inclination will be maintained within 0.1° of the equatorial plane, correction manoeuvres will consume about 7 kg of hydrazine each year, a mass of the same order as that of a repeater chain. For a 7 year lifetime, some 50 kg of fuel would be necessary. If orbit-inclination control can be dispensed with, a large portion of this mass can be used to expand the payload and

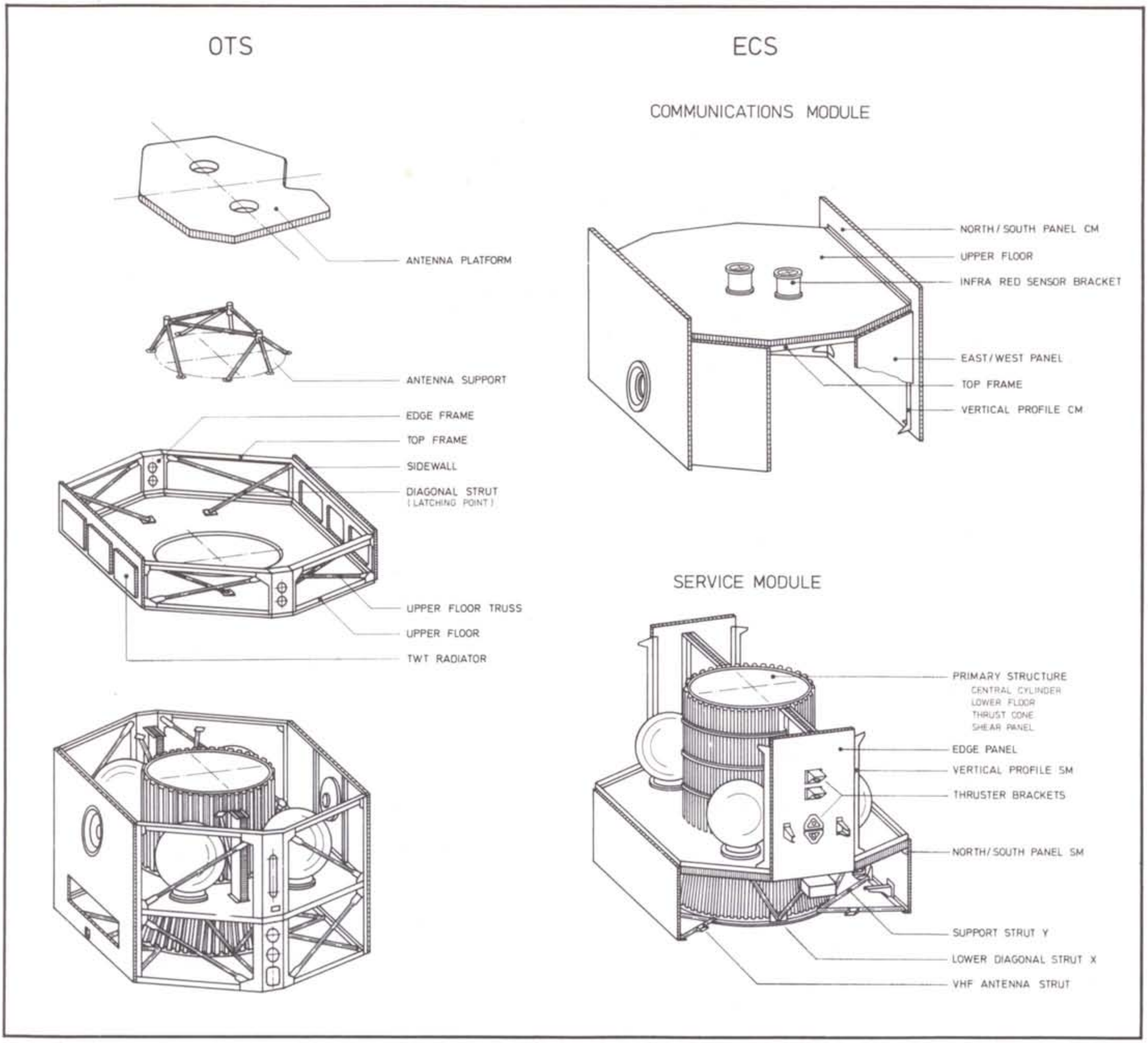

Figure 4 – Exploded views of OTS and ECS.

increase the satellite's communication capacity. Some of the mass saved must, however, be reallocated to the AOCS itself, since OTS's fixed momentum wheel must be replaced by a more complex device consisting of two skewed wheels and a reaction wheel, to give the increased flexibility required for attitude control in an inclined orbit.

In view of the magnitude of the projected demand for capacity on ECS, there appears to be no sound alternative to the trade-off described above. As the change in orbit inclination is slow and quite predictable, it will be possible to place the satellite initially in a slightly inclined geosynchronous orbit such that the natural drift will cause the inclination to decrease gradually to zero and then to increase again in the opposite direction. With the correct initial inclination of 3.5° and in the absence of any correction manoeuvres, the latitude of the subsatellite point will be maintained within ±3.5° throughout the satellite's projected 7 year lifetime. Stationkeeping manoeuvres will be restricted to maintaining the satellite within 0.1° of its assigned longitude; this will not require more than about 5 kg of hydrazine for the whole seven-year period.

Further changes will be a slight redesign of the structure

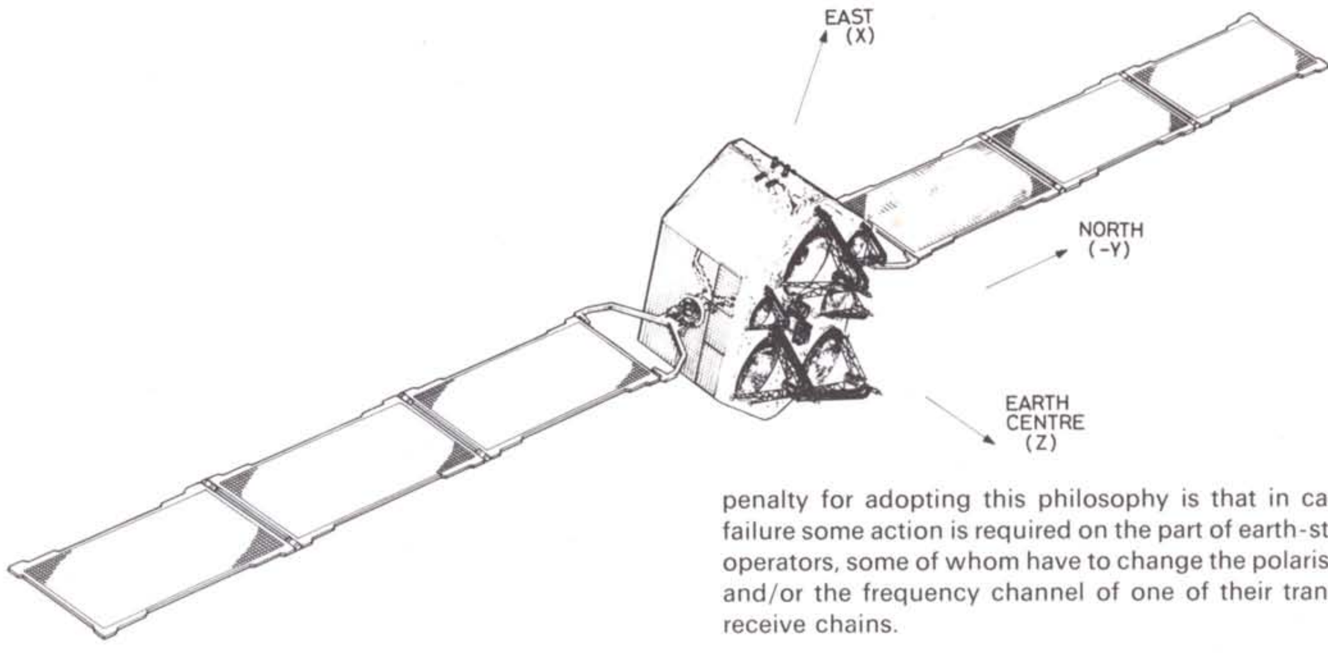

Figure 5 – ECS in orbital configuration.

of both service and communications modules (Fig. 4) in order to increase mass effectiveness and to achieve a more optimum configuration in view of the revised payload, and an extension of the solar arrays, which will then have three panels each instead of two (Fig. 5).

THE COMMUNICATIONS PAYLOAD

The communications module developed for OTS carries eight TWTAs each capable of delivering a maximum output power of 20 W. Up to six can be powered simultaneously under sunlight conditions and two during eclipses. Various ways of expanding the communications payload for ECS have been investigated and a preferred solution has been retained.

Extension of the solar-panel area by about 50% will enable the average prime power level to be raised from 600 to 900 W. The number of repeater chains which can be operated simultaneously under sunlight and eclipse conditions with this increased power depends on the one hand on the degree of redundancy adopted in the repeater subsystems, and on the other on the requirements for eclipse operation, which reflects on the weight of the batteries.

A comparative study of different approaches has shown that it is advantageous from the points of view of reliability and capacity to implement the maximum number of repeater chains with the minimum of redundancy inside individual chains. If this is done, and provided the necessary switching facilities are available, any unused chain can take over from a defective unit, thereby ensuring that, when the satellite is eventually saturated, all units capable of working are actually put into active use. The penalty for adopting this philosophy is that in case of failure some action is required on the part of earth-station operators, some of whom have to change the polarisation and/or the frequency channel of one of their transmit/receive chains.

With the redundancy philosophy just described, there is little point in sizing the satellite's power system such that enough power can be generated until end-of-life for all repeater chains available on board, since the probability that they will all remain operational for that length of time unavoidably falls short of 100%. It therefore makes sense to try to economise on this power system and to design its capability for only a fraction of the total number of repeater chains implemented.

Furthermore, the mass that needs to be allocated to batteries for keeping one 20 W repeater in operation throughout the longest eclipse (72 min) is of the same order as that of the repeater itself, i.e. 6 to 7 kg. A trade-off between total number of repeater chains and eclipse capability was therefore made, due consideration being given to possible repercussions in the way of operational problems.

As a result of the various trade-off investigations just described, a preferred solution has been defined in which at least nine of the twelve repeater chains available on board can be powered continuously during sunlit periods, but only five during eclipses. Given nine working chains, of which two are used for television transmissions, the satellite will be able to accommodate up to 12 000 telephone circuits.

With twelve repeater chains arranged to operate with frequency re-use in a total band of 500 MHz, switching facilities must be provided to change the connections between repeater outputs and transmitting antennas in order to implement the redundancy philosophy described. The switching system must, of course, take into account potential traffic growth in individual areas and be so designed as to offer sufficient flexibility to reconfigure the

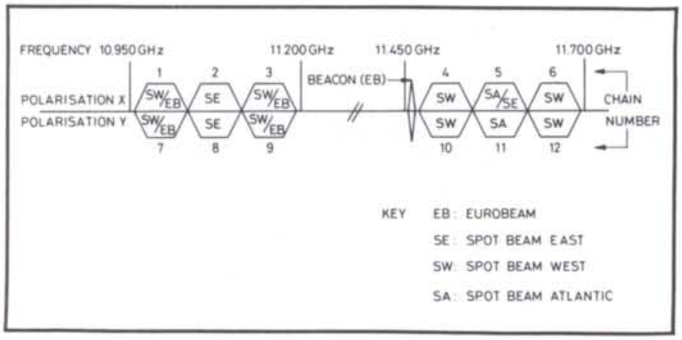

Figure 6 – Repeater output switching plan.

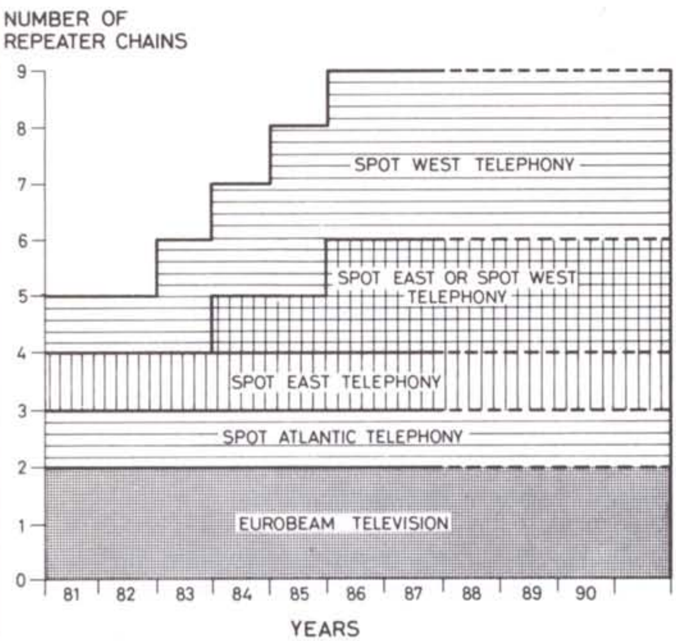

Figure 7 – Allocation of repeater chains in ECS system.

repeater subsystem in case of failure of up to three chains. Here again an optimum solution has been identified, which requires a switch at the output of five of the twelve chains. The corresponding frequency plan is shown in Figure 6. To guard against mutual interference due to frequency re-use, care will have to be taken not to use the same frequency channel simultaneously in two different beams, except in the Spot Atlantic and the Spot East which do not overlap.

IMPLEMENTATION OF THE SYSTEM

An agreement is currently being negotiated between the Agency and the newly born EUTELSAT organisation with a view to defining the terms of co-operation between these two bodies in respect of the implementation, management and operation of the space segment of the future ECS system. According to the proposal now under discussion, ESA will provide EUTELSAT with satellites of the type described above and will ensure that there are always two in orbit, one operational and one spare, each capable of satisfying the capacity requirements defined by the CEPT, albeit in sunlight conditions. It has been agreed that, when the satellites are in the Earth's shadow, it may not be possible to power more than five chains simultaneously. The telephone traffic to be accommodated at hours when eclipses occur will be fitted into three repeater chains, one for each Spotbeam area. The fourth chain will be allocated to Eurovision traffic through the Eurobeam, and the fifth on an ad-hoc basis to satisfy specific requirements.

The first of the ECS satellites will be launched in 1981, and will be followed by a second within a year. These could in principle furnish adequate capacity until the end of their design lifetime in 1987 and, if the requirements remain constant for a few more years as currently assumed, it should be possible to satisfy needs until the end of the decade by launching two more units. Present plans are to procure a total of five flight units, so as to have an additional spare as a contingency measure.

As for the earth segment of the system, it will be the responsibility of individual user Administrations to construct and operate their own earth stations. A typical station will comprise an antenna system with a reflector 14 to 18 m in diameter and a dual linearly polarised feed. A transmitter power of the order of 2 kW will be required. Uncooled low-noise preamplifiers with 150 K noise temperature will provide a Gain/Temperature (G/T) ratio of 38 to 40 dB (K^{-1}) in clear weather. Ten to fifteen stations are expected to be constructed throughout Europe when the system starts operating. Two have already been completed, in Italy at Fucino and in France at Bercenay-en-Othe, but these will first be used on an experimental basis with OTS. □

Le programme Symphonie

Y. de Coatpont, Programme franco-allemand Symphonie – Secrétariat exécutif français, CNES, Toulouse, France

Premier système européen de télécommunications par satellite, Symphonie est le fruit d'un programme de développement franco-allemand mené dans le cadre d'une convention signée en juin 1967 par les gouvernements français et allemand (RFA). Ce programme avait pour objet la conception, la réalisation, le lancement et l'utilisation d'un satellite expérimental de télécommunications destiné à distribuer des programmes de télévision, à assurer des communications téléphoniques et à transmettre des données.

La première phase de ce programme, consacrée au développement et à la mise en place du système, s'est achevée par le lancement réussi de deux satellites: Symphonie A le 19 décembre 1974, et Symphonie B le 27 août 1975. Lancés depuis le Kennedy Space Center sur Thor Delta 2914, les deux satellites ont été initialement mis à poste au-dessus de l'Océan Atlantique à 11,5° de longitude Ouest, par les centres de contrôle français (CNES) et allemand (DFVLR).

Plus de trois années se sont écoulées qui ont été mises à profit pour réaliser un vaste programme d'utilisations couvrant une grande variété d'expérimentations.

LE SYSTEME SYMPHONIE

SEGMENT SPATIAL

Le segment spatial se compose de deux satellites géostationnaires, Symphonie A et B, ayant les caractéristiques principales suivantes:

- masse 235 kg (à poste, en début de vie)
- énergie de bord 180 W (en fin de vie)
- maintien à poste ±0,5°
- durée de vie 5 ans,

et des stations de contrôle associées.

Les satellites se caractérisent, d'une part, par une stabilisation trois axes (– technique utilisée pour la

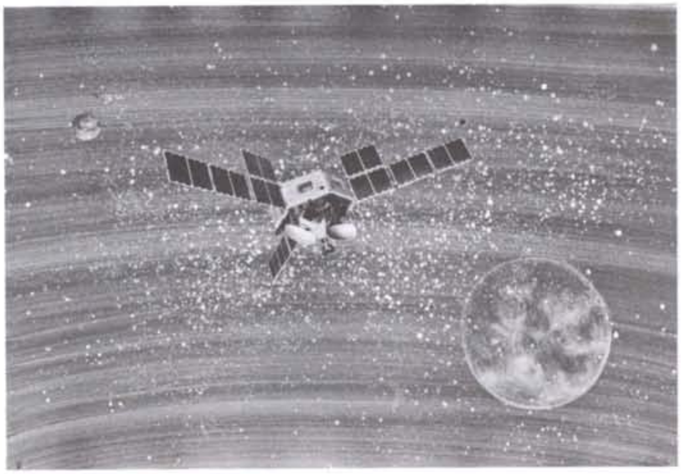

Figure 1 – Satellite Symphonie.

première fois sur un satellite de télécommunications civiles et assurant une grande précision d'attitude et de pointage des aériens –), d'autre part, par une charge utile fonctionnant dans la gamme 4/6 GHz; celle-ci comprend deux répéteurs à large bande (90 MHz) associés à deux antennes d'émission illuminant deux zones privilégiées permettant l'emploi de stations terriennes moyennes.

Le satellite Symphonie A a été déplacé et se trouve à poste au-dessus de l'Océan Indien à 49° de longitude Est depuis mai 1977. Il permet d'illuminer une zone euro-africaine et une zone asiatique centrée sur l'Inde.

Le satellite Symphonie B se trouve toujours à poste au-dessus de l'Océan Atlantique à 11,5° de longitude Ouest. Il permet d'illuminer une zone américaine et une zone euro-africaine.

La couverture assurée maintenant par Symphonie permet à un plus grand nombre de pays d'accéder au système.

Le contrôle des satellites en orbite est assuré par les centres de contrôle du CNES à Toulouse et du DFVLR à Oberpfaffenhofen, associés aux stations de contrôle VHF ou SHF de Toulouse, Kourou, Pretoria et Weilheim.

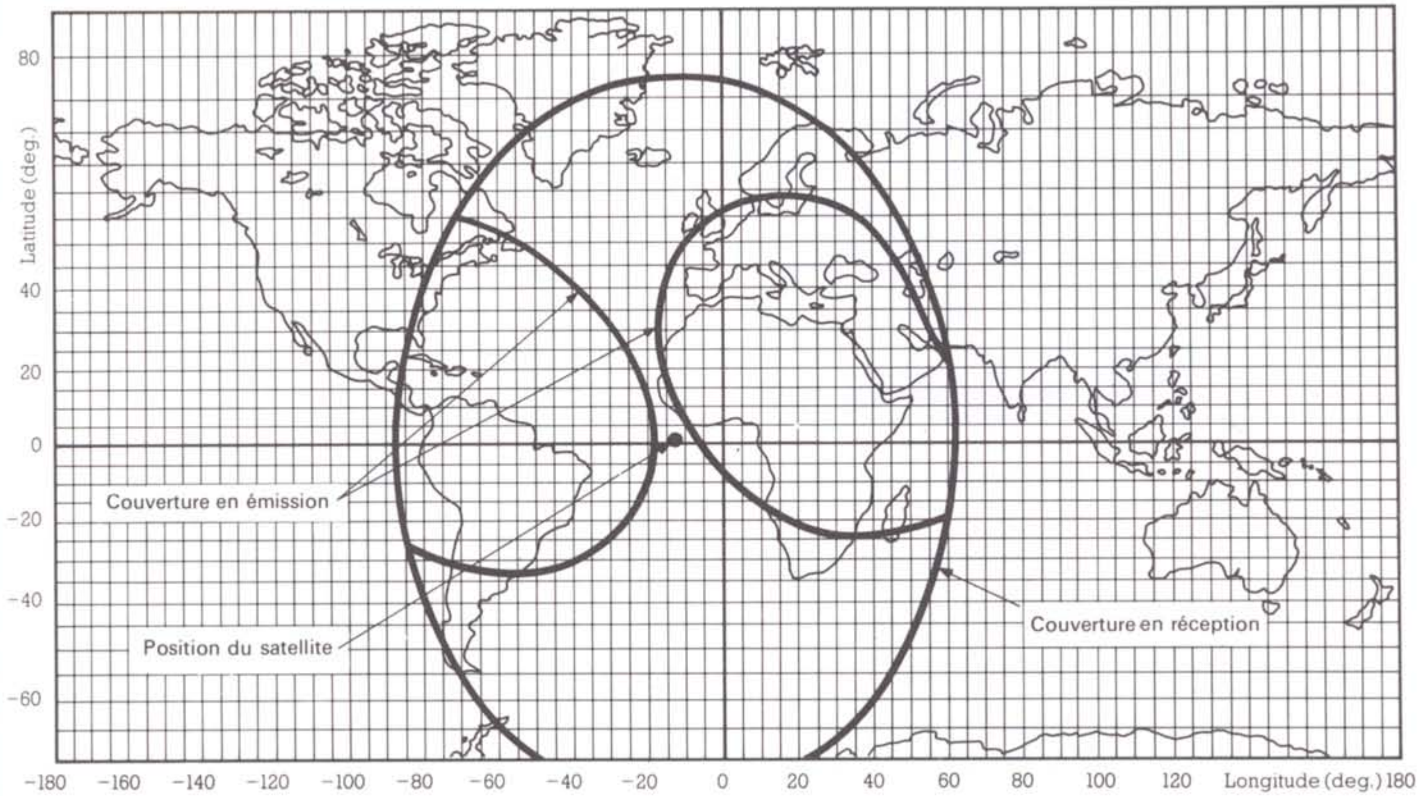

Figure 2 – Couverture Atlantique de Symphonie B.

SEGMENT SOL

Le segment sol qui comportait initialement les deux stations principales de Pleumeur-Bodou (France) et Raisting (RFA) s'est considérablement développé et diversifié: une quarantaine de stations de différents types installées dans 20 pays sont reliées à Symphonie de façon temporaire ou permanente. On peut distinguer trois grandes classes de stations:

- les *stations principales* (Pleumeur-Bodou, Raisting, la Réunion) équipées d'antennes de 15 m environ, à pointage automatique, d'amplificateurs paramétriques non refroidis, d'amplificateurs de puissance de 3 kW et ayant une sensibilité de 31,5 dB/K.
- les *stations moyennes*, transportables, équipées d'antennes de 8,80 m, d'amplificateurs paramétriques non refroidis et ayant une sensibilité de 28 dB/K, utilisées principalement pour les transmissions de télévision; ces stations peuvent être utilisées soit en émission grâce à l'adjonction d'un émetteur de 1 kW soit en simple réception.
- les *petites stations* transportables équipées d'antennes de 4,80, 4,50 ou 3,30 m, d'amplificateurs paramétriques non refroidis, et ayant une sensibilité de 20 à 24 dB/K; ces stations sont utilisées généralement pour des liaisons téléphoniques de faible capacité nécessitant des amplificateurs de 50 à 250 W selon le nombre de circuits. Des démonstrations de réception de télévision à l'aide de stations de 4,50 m ont été réalisées avec succès dans des régions favorisées par un plus grand flux émis par le satellite.

Un inventaire complet de ces stations figure au Tableau 1.

COMPORTEMENT DES SATELLITES EN ORBITE

Dès la mise à poste des satellites, un programme complet de mesure des performances des différents sous-systèmes a été mené; les résultats ont montré le bon fonctionnement général des deux satellites et la tenue des spécifications avec des marges substantielles. Aujourd'hui, soit environ trois ans et demi après le lancement de Symphonie A et trois ans après celui de Symphonie B, le comportement en orbite des deux satellites est tout à fait satisfaisant.

PERFORMANCES DU VEHICULE

Les fonctions les plus importantes sont les liaisons de télémesure et télécommande, le contrôle thermique, l'alimentation en énergie électrique et la stabilisation.

Le système de *télémesure et télécommande* VHF et SHF fonctionne dans les conditions prévues. Toutefois, des anomalies sporadiques affectant les circuits numériques

TABLEAU 1

Stations utilisées dans le système Symphonie (situation en avril 1978)

ORIGINE	AFFECTATION	DIAMETRE D'ANTENNE (m)	SERVICE	ENTREE EN SERVICE
Pool franco-allemand	Pleumeur-Bodou	16,5	Tph, E/R TV	1974
Symphonie	Raisting	15,5	Tph, E/R TV	1974
	Bouaké (Côte d'Ivoire)	8,8	R TV	1976
	Franceville (Gabon)	8,8	R TV	1977
	Téhéran (Iran)	8,8	E/R TV	1977
	Shiraz (Iran)	8,8	R TV	1977
	Tripoli (Libye)	8,8	E/R TV	1977
	Le Caire (Egypte)	8,8	R TV	1978
France	Pleumeur-Bodou 2	28,5	Tph, E/R TV	1976
	La Réunion	14,5	Tph, E/R TV	1976
	Abidjan (Côte d'Ivoire)	8,8	Tph, E/R TV	1978
	St. Pierre-et-Miquelon	8,8	R TV	1977
	Asssouan (Egypte)	4,8	Tph	1978
	en attente (Samson)	4,8	Tph	1975
	embarquée sur navire	2,2	Tph	1978
Allemagne	Kigali (Ruanda)	4,5	Radio	1976
	Le Caire (Egypte)	4,5	Tph	1978
	Djeddah (Ambassade)	3,3	Tph	1978
	en attente (Croix Rouge)	3,3	Tph	1978
ONU	Jérusalem	4,5	Tph	1976
	Genève	4,5	Tph	1977
	Ismailia	4,5	Tph	1978
	en attente	3,3	Tph	1978
Inde	Ahmedabad	14	Tph E/R TV	1977
	Delhi	10,7	Tph E/R TV	1977
	Madras	10,7	Tph E/R TV	1977
	mobile	6,1	Tph E/R TV	1977
	mobile	3	Tph	1977
Canada	Ottawa	8	E/R TV	1975
	Montréal	8	E/R TV	1976
USA	Gaithersburg	4,5	Données	1977
URSS	Moscou	10	E/R TV	1975
Espagne	Aguimes	30	Tph	1976
Pays-Bas	Hilversum	4,5	Tph	1976
Finlande	Helsinki	13,7	R TV	1976
Norvège	Swalbard	4,5	Tph	1976
Belgique	Anvers	4,5	Tph	1977
Arabie Saoudite	Riad	4,5	Tph	1977

du récepteur de télécommande ont été enregistrées sur les deux satellites, mais n'ont heureusement aucune conséquence grave. La recherche des causes a montré qu'il s'agissait vraisemblablement de phénomènes de charges statiques dues au milieu spatial. De nombreux autres satellites géostationnaires ont été affectés par cette anomalie.

L'évolution des températures des différents équipements n'a pas montré de variations moyennes supérieures à quelques degrés depuis le lancement; ce résultat confirme la bonne conception du *contrôle thermique* des satellites, rendu particulièrement délicat dans le cas d'une stabilisation trois axes, ainsi que la bonne tenue des revêtements thermiques; on note cependant un vieillissement de ces revêtements légèrement plus rapide que prévu.

Le générateur solaire de type fixe, équipé de 22 000 cellules, a été conçu pour délivrer une *puissance* maximale de 300 W en début de vie et une puissance minimale de 180 W après cinq ans de fonctionnement. L'évolution de cette puissance depuis le lancement est conforme aux prévisions théoriques. Par ailleurs, deux batteries redondantes assurent la fourniture d'énergie pendant les périodes d'éclipse; sur Symphonie A, l'une d'entre elles est hors service, vraisemblablement à la suite d'un court-circuit interne. Cet incident n'affecte pas le fonctionnement général du satellite.

Le système de *stabilisation* assure le contrôle d'orbite à l'aide de sept propulseurs à gaz chaud (biergol) commandés depuis le centre de contrôle, ainsi que le contrôle d'attitude à l'aide d'une roue à inertie unique associée à des senseurs infrarouges et huit propulseurs à gaz froid (azote). Le maintien à poste, spécifié dans une fenêtre de $\pm 0,5°$ en Nord-Sud et en Est-Ouest est en fait assuré à $\pm 0,25°$ sans augmentation de la consommation d'ergols et pourrait être porté sans difficulté à $\pm 0,1°$.

La précision du contrôle d'attitude est meilleure que 0,3°; l'erreur de tangage détectée par le senseur infrarouge est corrigée en permanence par la boucle d'asservissement correspondante; l'erreur de roulis-lacet est corrigée une fois par semaine à l'aide du système gaz froid commandé depuis le centre de contrôle.

La consommation de gaz froid, estimée d'après l'évolution des pressions dans les réservoirs, est légèrement inférieure aux prévisions. La réserve disponible pourrait assurer dans les conditions actuelles un fonctionnement de sept à huit années. Les réserves de gaz chaud sont moins importantes mais suffisantes pour assurer la durée de vie nominale de cinq ans.

Une anomalie a été décelée sur une des deux branches du système de gaz chaud de Symphonie B; elle se traduit par de légères poussées intempestives qui perturbent l'attitude du satellite. Cette branche a été isolée et l'étude du phénomène se poursuit sans que la mission soit actuellement affectée.

PERFORMANCES DE LA CHARGE UTILE

La mesure des caractéristiques de transmission des répéteurs du satellite en orbite a été effectuée à partir des stations principales de Pleumeur-Bodou et de Raisting. Les résultats sont très positifs et montrent que les spécifications sont largement tenues. Ainsi la PIRE (Puissance Isotrope Rayonnée Equivalente) de Symphonie A, en limite de couverture, est supérieure à 29,9 dB W pour le premier répéteur et supérieure à 30,3 dB W pour le second, qu'il faut comparer à la spécification de 29 dB W.

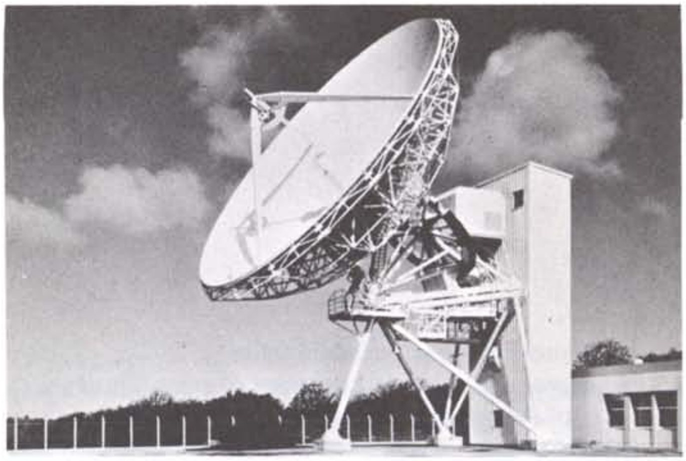

Figure 3 – Station Symphonie de Pleumeur-Bodou (France).

La sensibilité de réception, en limite de couverture, est de −13,7 dB/K et de −13,3 dB/K respectivement pour chacun des deux répéteurs de Symphonie A qu'il faut comparer à la spécification de −15 dB/K.

Les autres mesures effectuées qui concernent les distorsions linéaires et non linéaires, la stabilité de la fréquence de transposition et du gain des répéteurs ont donné d'excellents résultats. Le comportement en orbite des quatre répéteurs est excellent; le seul incident a été la panne d'un oscillateur local survenu sur Symphonie A peu après son lancement; il a été remplacé par l'équipement en redondance.

UTILISATIONS DU SYSTEME SYMPHONIE

Les objectifs assignés aux programmes d'utilisation des deux satellites découlent des termes de la Convention franco-allemande de 1967. Il s'agit de poursuivre en commun l'utilisation du système sur une base expérimentale pour appuyer les recherches techniques et scientifiques dans le domaine des télécommunications, pour expérimenter de nouveaux types d'utilisation, et pour faire connaître par des coopérations avec des pays tiers les qualités techniques des réalisations de l'industrie européenne.

Les accords passés avec la NASA pour la fourniture des lanceurs et les accords INTELSAT limitent le domaine des utilisations et excluent toute exploitation commerciale ou sur une base opérationnelle continue avec garantie de service.

Le programme d'utilisation s'est développé selon les quatre axes suivants:

Figure 4 – Station de 3 m installée à Jérusalem au profit de l'ONU.

- les démonstrations occasionnelles
- les expérimentations techniques et scientifiques
- les expérimentations à caractère culturel, humanitaire et éducatif
- les utilisations à caractère semi-opérationnel.

DEMONSTRATIONS OCCASIONNELLES

Organisées à l'occasion d'événements particuliers ou de manifestations importantes, ce sont des opérations de courte durée destinées à démontrer devant un large public les possibilités offertes par Symphonie à l'aide de diverses stations mobiles. Dans ce domaine, on peut citer:

- les premières démonstrations réalisées à l'occasion du Salon du Bourget en 1975 où furent présentées en fonctionnement la station Samson équipée d'une antenne de 4,80 m et d'un modem numérique 2 Mbit/s permettant la transmission avec la station de Pleumeur-Bodou de 30 circuits téléphoniques ou d'un canal visiophonique, ainsi que la première station de réception de télévision éducative équipée d'une antenne de 8,80 m;
- la présentation à Genève à l'occasion de TELECOM 75 d'une petite station équipée d'une antenne de 3 m, permettant la transmission d'un circuit téléphonique avec une station principale;
- la démonstration à Montréal en 1976 dans le cadre du Congrès de l'AIAA/CASI d'une liaison téléphonique par 'double bond' entre une station équipée d'une antenne de 3 m située à Jérusalem et une station canadienne de Téléglobe équipée d'une antenne de 10 m;
- la présentation d'une petite station de réception de télévision équipée d'une antenne de 4,5 m à l'occasion de l'exposition de Téhéran en 1976, de la Foire de Hanovre en 1977 et de l'Assemblée générale de l'URTNA à Lomé, Togo, en 1978;
- la présentation à Dublin en mai 1977 à l'occasion du Symposium organisé par l'ESA et l'UER d'une petite station de réception de télévision équipée d'une antenne de 4,5 m et recevant des émissions en provenance de France (Pleumeur-Bodou), d'Allemagne (Raisting et Munich) et du Canada (Ottawa);
- la présentation, à l'occasion du Salon du Bourget en juin 1977, d'une nouvelle station d'émission/réception de télévision équipée d'une antenne de 8,80 m et d'une émetteur de 1 kW.

EXPERIMENTATIONS TECHNIQUES ET SCIENTIFIQUES

C'est le domaine privilégié de Symphonie. En effet, par sa vocation expérimentale, ce système est affranchi de toute contrainte d'ordre opérationnel. Il représente donc un banc d'essai idéal pour expérimenter, mettre au point et vérifier dans des conditions réelles d'utilisation, toutes sortes de procédures, de techniques et d'équipements nouveaux de télécommunications spatiales dans la gamme 4-6 GHz avant leur application et leur mise en service dans des systèmes opérationnels. Certaines restent dans le domaine des télécommunications classiques (téléphonie, télévision), d'autres ouvrent la voie à des applications futures (synchronisation, liaisons entre calculateurs) comme le montrent les exemples donnés ci-dessous:

Le programme expérimental franco-allemand

C'est l'expérimentation de base du système Symphonie conduite en coopération franco-allemande. Destiné à une évaluation complète du système, ce programme a débuté dès la mise en service de Symphonie A à l'aide des deux stations principales de Pleumeur-Bodou et de Raisting. Il a permis d'évaluer la capacité réelle du système en transmission téléphonique et télévisuelle.

En téléphonie, le programme a d'abord comporté des essais en modulation de fréquence analogique: essai en monoporteuse permettant de définir les paramètres optimaux (excursion de fréquence et puissance d'émission des stations), puis essai en multiporteuse (accès

Figure 5 – Démonstration du système Symphonie au cours du Symposium ESA-UER, Dublin (Irlande).

multiple par répartition en fréquence); dans cette dernière configuration, la capacité obtenue est de 750 voies téléphoniques par répéteur avec un rapport signal sur bruit supérieur à 51 dB. Des essais en téléphonie numérique ont également été conduits: transmission de porteuses modulées par déplacement de phase, de capacité 1 voie, 12 ou 24 voies, constituées à partir d'un multiplex TN.1 (2 Mbit/s). Enfin, des essais de transmission téléphonique en accès multiple par répartition dans le temps ont débuté en 1977; l'effet des distorsions sur le taux d'erreur d'un train numérique à 60 Mbit/s émis par paquets a été mesuré, ainsi que l'amélioration apportée par l'adjonction d'un dispositif de linéarisation dans la chaine d'émission de la station terrienne.

Les essais de transmission de télévision ont été effectués en modulation de fréquence analogique: ils ont permis de déterminer les paramètres de transmission optimaux dans le cas où une seule porteuse vidéo transite par l'un des répéteurs du satellite. Ces essais ont ensuite été complétés par la transmission simultanée dans le même répéteur de deux, puis de trois porteuses video, sans qu'une dégradation de la qualité de l'image ne soit perceptible.

Transmission de télévision numérique

Une démonstration de transmission de télévision en codage numérique a eu lieu en avril 1977 à Venise à l'occasion d'un colloque organisé par l'UER; les émissions en provenance de Rennes, via Pleumeur-Bodou, étaient reçues à l'aide d'une station transportable équipée d'une antenne de 8,80 m de diamètre.

Le programme experimental indien (STEP)

Dans le cadre d'une convention établie entre Symphonie et l'Inde, l'ISRO (Indian Space Research Organisation) dispose, depuis le 1 er juin 1977 et pour une durée de deux ans, d'un répéteur afin de réaliser un vaste programme expérimental dans le domaine de la téléphonie et de la télévision à l'aide de trois stations principales de 11 m et plusieurs stations secondaires transportables de 3 à 5 m. Les enseignements tirés de cette expérience serviront en particulier à définir les caractéristiques du futur réseau national indien.

Le programme expérimental iranien

Une convention a été signée en 1977 avec la NIRT qui doit effectuer via Symphonie des essais techniques et opérationnels de transmission de télévision et de téléphonie. A cet effet, deux stations ont été mises à la disposition de l'Iran à Téhéran et à Shiraz. La mise à disposition de Symphonie a été inaugurée officiellement en février 1978 par un télédialogue au niveau des Chefs d'Etat entre Paris, Bonn et Téhéran.

Synchronisation d'horloges atomiques à l'échelle intercontinentale

Proposée par le Bureau International de l'Heure, cette expérimentation est particulièrement prometteuse pour les applications futures. L'objectif est de définir et de mettre au point une méthode de mesures permettant la synchronisation d'horloges atomiques à l'échelle intercontinentale à l'aide d'une liaison par satellite.

Liaison à grande cadence entre calculateurs

A l'aide de deux stations implantées à proximité de centres de calcul, l'un en France, l'autre aux Etats-Unis, une liaison à grande cadence (1,5 Mbit/s) a été établie en 1977 pendant quatre mois. Cette expérimentation préfigure les futurs systèmes de téléinformatique constitués de satellites reliant des calculateurs de grande puissance. Une deuxième phase est à l'étude.

Autres expérimentations techniques

D'autres expérimentations sont en cours. On peut citer:

- la mise au point de nouvelles procédures de signalisation téléphonique (Allemagne – Espagne)
- de nombreux essais de mise au point de transmission par porteuse monovoie utilisant soit la modulation de fréquence, soit la modulation par déplacement de phase associée à un codage MIC ou Delta.

EXPERIMENTATIONS A CARACTERE CULTUREL, EDUCATIF ET HUMANITAIRE

Il s'agit là aussi d'un domaine d'utilisation privilégié de Symphonie. A cela, deux raisons essentielles:

- la nature expérimentale de Symphonie le rend tout à fait apte à remplir ce genre de missions à caractère non lucratif, faites au bénéfice d'organismes internationaux ou de pays en voie de développement;
- le concept relativement ancien (une dizaine d'années) d'utiliser les satellites aux fins d'éducation et qui a donné naissance à la technique de télévision éducative par satellite.

Les expérimentations suivantes sont en cours:

Télévision éducative en Afrique

Tirant profit des études réalisées en France, un programme expérimental de télévision éducative au profit des pays africains est en cours de réalisation grâce à Symphonie par la mise à disposition, non seulement de la capacité de répéteur nécessaire, mais aussi de stations spécialement développées pour cette mission (stations de télévision éducative).

- La première application de ce programme a débuté en Côte d'Ivoire il y a deux ans: une station de télévision éducative installée au complexe d'enseignement télévisuel de Bouaké, et exploitée par le personnel local permet de recevoir des programmes pédagogiques existant en France et en Allemagne fédérale. Sélectionnés par une Commission mixte franco-germano-ivoirienne, ces programmes sont transmis à raison d'une trentaine d'heures par mois par les stations de Pleumeur-Bodou et de Raisting. Stockés sur place, ils viennent en complément de la production locale pour alimenter les quelque 5000 écoles primaires ivoiriennes équipées de téléviseurs. Une deuxième phase, plus ambitieuse, mettant en jeu une station d'émission/réception implantée à Abidjan va débuter sous peu.
- La deuxième application a débuté au Gabon; une station de réception de télévision installée en 1977 à Libreville a été mise à la disposition des services de l'Education Populaire et est associée au réseau déjà existant des 'cases d'écoute'.

L'intérêt suscité par ces deux premières réalisations laisse entrevoir une extension prochaine du nombre d'expérimentations de ce type au profit d'autres pays, préfigurant la mise sur pied d'un véritable réseau régional africain.

Expérimentation ONU

Les Nations-Unies ont manifesté depuis longtemps leur grand intérêt pour l'utilisation des satellites de télécommunications dans le cadre des missions humanitaires (maintien de la paix, secours en cas de catastrophes naturelles, etc.). Depuis février 1976, le détachement de l'ONU à Jérusalem était relié à son Etat-Major à Genève grâce à une station de 3 m qui y est implantée; la liaison s'effectuait jusqu'à présent par voie spatiale jusqu'à Raisting puis par faisceau hertzien jusqu'à Genève. Depuis peu, une station de 4,5 m implantée à Genève permet une liaison directe, tandis qu'une troisième station va être installée à Ismaïlia. Enfin une quatrième, transportable, va être mise à la disposition de l'ONU qui l'utilisera pour établir rapidement une liaison avec Genève en cas d'urgence.

Expérimentation UNESCO

La XVIIIème Conférence générale de l'UNESCO devant se tenir à Nairobi (Kénya) du 26 octobre au 30 novembre 1976, cette organisation a saisi cette occasion pour réaliser une expérimentation particulièrement originale: il s'agissait en effet, au moyen de diverses liaisons directes entre le Siège de l'UNESCO à Paris et le lieu de la Conférence, d'évaluer dans quelle mesure les activités de fonctionnement de l'Organisation et les activités liées au déroulement de cette Conférence pourraient être assurées à distance (secrétariat, presse, échanges d'information et de données). Pour répondre à cette demande, des moyens importants furent mis en oeuvre avec le concours des PTT français:

- la station Samson, d'une capacité de 30 voies téléphoniques numériques et équipée du dispositif de visiophonie, installée sur le lieu de la Conférence
- une liaison spécialisée, à haute cadence (2 Mbit/s) reliant la station de Pleumeur-Bodou au Siège de l'UNESCO à Paris
- un ensemble de terminaux appropriés (télex, facsimilé, visiophones) installés à Nairobi comme à Paris
- la capacité de répéteur correspondante.

Ainsi, pendant toute la durée de la Conférence, l'UNESCO disposa à raison de 12 heures par jour, de liaisons directes répondant parfaitement aux exigences principales de qualité et d'instantanéité.

EXPERIMENTATIONS A CARACTERE SEMI-OPERATIONNEL
En dépit des apparences, ce type d'utilisation n'est pas en contradiction avec la nature expérimentale de Symphonie. Il s'agit, en effet, à l'exception de la garantie de continuité du service (à laquelle on remédie en prévoyant les secours appropriés), de vérifier l'aptitude du système à satisfaire les contraintes propres aux liaisons opérationnelles (strict respect des horaires, maintien de la qualité...).

Sur un plan purement technique, c'est là une source d'enseignements statistiques, irremplaçables sur la tenue des performances de l'ensemble des moyens mis en jeu, satellites et stations terriennes. Dans ce domaine, quatre exemples peuvent être cités:

Liaison France métropolitaine-Ile de la Réunion
Depuis le 10 octobre 1976, la totalité des liaisons de télécommunications entre la France métropolitaine et le département de la Réunion est assuré 24 heures sur 24 par Symphonie B, à savoir:
- le trafic téléphonique permanent (120 circuits)
- les transmissions quotidiennes de programmes de télévision.

On utilise la station Symphonie de Pleumeur-Bodou et la station de 14,5 m implantée à Saint-Denis de la Réunion. Durant les périodes d'éclipse, ou en cas de défaillance de Symphonie, le secours est assuré par un répéteur Intelsat loué par les PTT français.

Radiodiffusion de Kigali
Cette expérimentation, conduite par la Deutsche Welle (organisme de radiodiffusion de la RFA) consiste à acheminer par Symphonie les programmes radio vers l'émetteur de langue allemande situé à Kigali (Ruanda) en parallèle avec la liaison HF courante. Les transmissions inaugurées en avril 1976 sont réalisées par la station de Raisting à raison de 7 à 8 heures par jour.

Liaison France métropolitaine-Ile de Saint-Pierre et Miquelon
Le département français de St.-Pierre et Miquelon reçoit des programmes de télévision transmis quotidiennement à partir de la station de Pleumeur-Bodou et relayés par Symphonie B. La station de réception a été installée à St.-Pierre en septembre 1977.

Liaison le Caire – Assouan
Depuis le début de l'année, le trafic téléphonique entre le Caire et Assouan est acheminé par Symphonie. L'installation des stations terriennes, des faisceaux hertziens de raccordement et l'interconnexion au réseau téléphonique égyptien ont été effectuées en décembre 1977. Ce service a été inauguré le 30 janvier 1978 par le Ministre égyptien des Télécommunications.

CONCLUSION

L'analyse de ces premières années d'utilisation permet d'en tirer quelques enseignements.

La période écoulée constitue la démonstration indiscutable de la qualité technique de Symphonie. On peut ajouter qu'à bien des égards, sa conception comme sa technologie sont loin d'être dépassées (couverture régionale, stabilisation sur trois axes, etc.).

L'augmentation progressive et la diversité des expérimentations réalisées ou en projet traduisent clairement tout l'intérêt que représente un tel système: banc d'essai irremplaçable pour la mise au point de techniques nouvelles de télécommunication, instrument de coopération avec des pays en voie de développement, qui découvrent ainsi les possibilités des systèmes spatiaux.

Enfin, Symphonie contribue de façon importante à la promotion du savoir-faire et de la technologie européenne dans la compétition en matière de systèmes de télécommunications spatiales. Compte tenu des contraintes qui pèsent sur le système, telles que les limitations d'emploi imposées par le respect d'accords internationaux, l'absence de continuité du service (il s'arrêtera lorsque les deux satellites cesseront de fonctionner vers 1980) ou encore la modestie du budget alloué au développement de stations d'utilisation Symphonie, on peut sans aucun doute présenter un bilan positif. Résultat encourageant qui ne peut qu'inciter les responsables français et allemands à poursuivre leurs efforts communs pour continuer de développer les utilisations de Symphonie en recherchant avant tout la diversité et l'originalité. □

The Sirio Programme — Its Mission and Experiment Objectives

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The Italian National Research Council has assigned its country's Sirio spacecraft communications programme three main objectives; namely
- **to conduct telecommunication experiments to examine propagation phenomena at frequencies of 12–18 GHz and analogue and digital data and television transmissions**
- **to qualify the basic spacecraft for geostationary missions**
- **to improve industrial capacity at system level and to develop advanced space technologies.**

The spin-stabilised satellite (Fig. 1) that constitutes the central element of the programme was launched by NASA from Cape Canaveral on 25 August 1977.

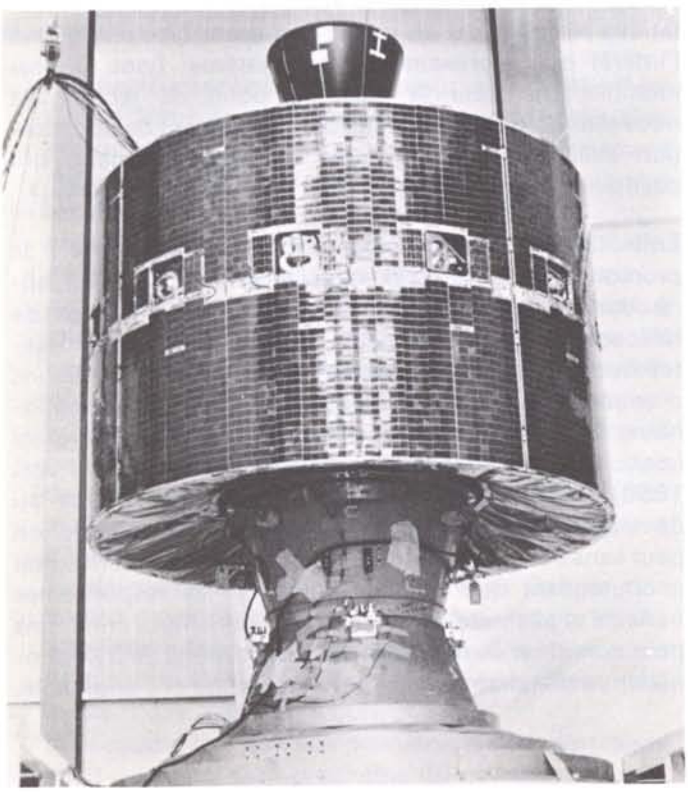

Figure 1 – Sirio spacecraft undergoing vibration testing at ESTEC.

THE COMMUNICATION PAYLOAD AND ITS EXPERIMENTAL CAPABILITIES

The experimental SHF telecommunications package, carried on the lower spacecraft platform (Fig. 2), consists of a transponder with three separate channels – one for propagation experiments and two for broad- and narrow-band communication experiments. For the propagation experiments, in the uplink two lateral bands spaced by 386 MHz from the suppressed carrier at 17.39 GHz, and in the downlink two lateral bands spaced by 265 MHz from the carrier at 11.59 GHz are used. The communication experiment carrier frequencies are 17.10 GHz for the uplink and 11.52 GHz for the downlink. The telemetry frequency is 11.47 GHz. Three coverage areas have been defined for Sirio's mechanically despun antenna, as shown in Figure 3, covering Italy, Central Europe, and Europe as a whole and the East Coast of North America, respectively. The propagation experiments are given priority and it is presently foreseen that at least 90% of the satellite's lifetime will be devoted to them. The communication experiments will be performed in the time remaining, but will be increased in extent if the satellite's lifetime proves to be more than the expected two years. The frequencies adopted for the experiments are shown in Figure 4, where the bands internationally assigned to commercial satellite communication systems are also indicated. The lower frequencies used in the Sirio experiments correspond to the downlink portion of the 11–14 GHz band, whilst the higher frequencies are at the lower edge of the downlink portion of the 20– 30 GHz band.

PROPAGATION EXPERIMENTS

The SHF transponder carried by Sirio allows five propagation parameters to be measured:
- absolute attenuation at 18 GHz
- differential attenuation at 18 GHz
- absolute attenuation at 12 GHz
- differential attenuation at 12 GHz
- phase distortion at 12 GHz.

In addition, a number of new experiments have recently been introduced: these are

- measurements of cross-polarisation coupling due to rain
- measurements of space-diversity improvement with a small, transmit-only station (installation foreseen near Fucino). This experiment, at 18 GHz, has been introduced as a modification of the test at 12 GHz originally foreseen, because more sensitive measurements are possible at 18 GHz, and in addition this method will be used extensively for systems working in the 20–30 GHz band
- measurements of the effects of rain scattering on received signal components, similar to the scattering interference measurements for the terrestrial links.

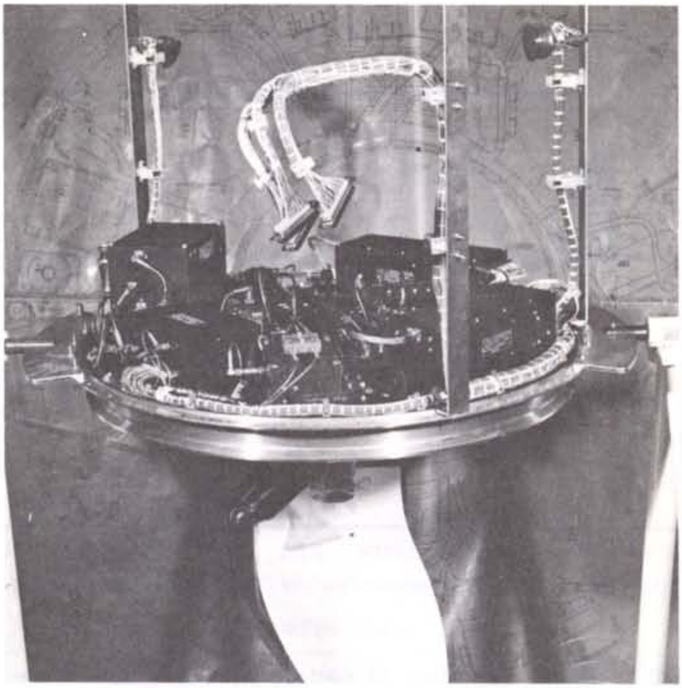

Figure 2 – Sirio's SHF telecommunications experiment package.

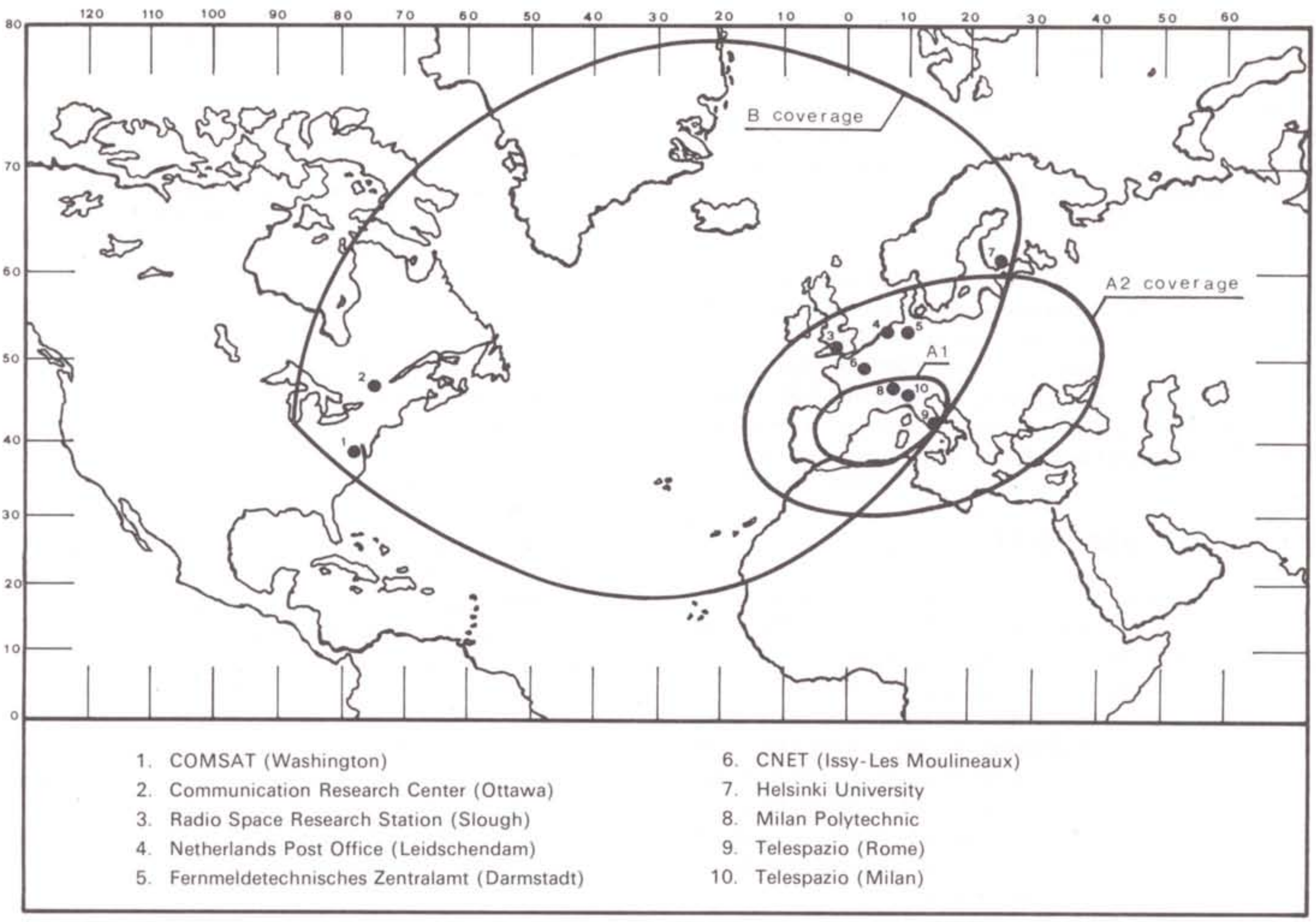

Figure 3 – Sirio coverage areas. A1 = Italy, A2 = Europe and B = Europe/USA.

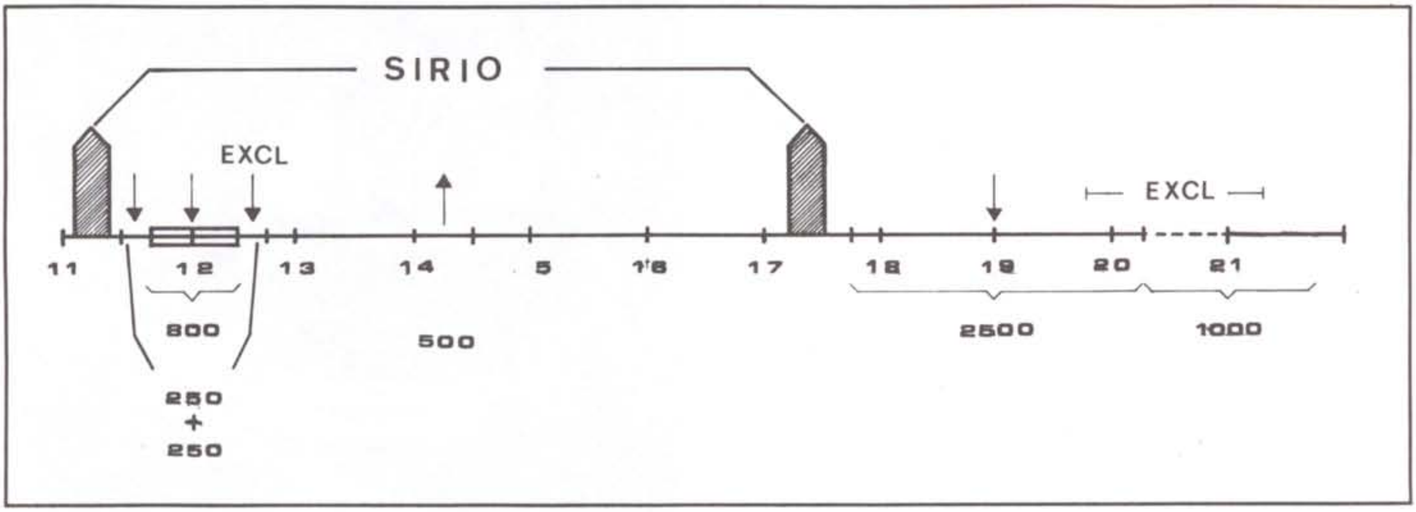

Figure 4 – Frequencies adopted for the Sirio programme compared with the internationally assigned frequencies for satellite communications.

Other bodies intending to participate with CNR in the Sirio propagation experiment programme include the Italian Navy (with a ship-board receiving station) and Universities and Research Institutes in the United Kingdom, the USA, West Germany, Austria, The Netherlands and Finland.

COMMUNICATION EXPERIMENTS

For the communication experiments, the Sirio transponder has two configurations, narrow-band and broad-band. The first, with a bandwidth of 1.5 MHz (at 1 dB), is to be used mainly for data-transmission and facsimile experiments. The second configuration, in which the available bandwidth is 34 MHz (at 1 dB), will be used for experimental television transmissions (both analogue FM and digital transmissions). In particular, the digital transmissions will test a new method and newly developed equipment capable of reducing redundancy for monochrome TV signals, down to a minimim transmission rate of 8.5 Mbit/s.

THE SIRIO SPACECRAFT

The Sirio satellite itself is cylindrical, about 1.4 m in diameter, 1.99 m high and weighs about 400 kg. Its expected orbital lifetime in geostationary position at 15°W is two years, with 73% reliability at end of life. The spacecraft is equipped with redundant telemetry command and ranging subsystems operating in the VHF band, and attitude control is provided by a hydrazine auxiliary propulsion system and sun and earth sensors. Electrical power is supplied by a solar generator with an end-of-life output of 120 W. Two (for redundancy) battery packages are available for eclipse operations.

Following the launch from Cape Canaveral by a 2313 Delta launch vehicle, a solid fuel (polybutadiene composite) apogee boost motor, with a specific impulse of more than 280 s and giving a velocity increment of 1648 m/s, carried on board the spacecraft was used to place the satellite into geostationary orbit.

SIRIO GROUND SEGMENT

For launch operations and until it reached its final position at 15°W, Sirio relied on NASA's STDN network, in conjunction with the Fucino and San Marco VHF ground stations. During the spacecraft's geostationary orbital phase, the Fucino VHF ground station and associated operational Control Centre were used. The latter Centre is designed to receive telemetry both from the VHF earth station and the two SHF communication earth stations at Fucino and Lario (northern Italy) and to transmit commands to the spacecraft only on VHF. The orbital position of the spacecraft during its operational lifetime is obtained from the pointing angles of the two SHF antennas. A third small earth station being installed at Spino d'Adda, near Milan, will be devoted solely to propagation experiments. A meteorological radar, to be used to correlate the propagation and atmospheric data, is available in the same area.

The main SHF stations are equipped with 17 m diameter azimuth-elevation mount autotrack antennas, and have redundant receiving/transmitting chains. The SHF data acquired by both stations are processed locally and stored, for further scientific analysis, on magnetic tape. □

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