TRENDS IN THE CONTROL AND MONITORING OF FUTURE EUROPEAN SATELLITES[1]

F. FIORICA
European Space Agency
ESTEC, the Netherlands

Summary. Current and future programmes of the European Space Agency (ESA) consist of relatively few missions but widely diversified in nature. The control and monitoring operations can be performed using either a specialized common band or the different payload frequency bands as assigned to each mission. The trade-off is discussed in the paper and considerations for the choice of the most suitable band presented. Some features of the preferred approach both for the ground and the space segments are illustrated as well.

Introduction. Most European satellites orbiting up to now carry scientific payloads. The latest of the series is COS-B, successfully launched in mid 1975. The frequency band used for communication with ground has been VHF both for spacecraft and experiments data.

Approved programmes are no longer restricted to scientific satellites but include also application oriented missions in the field of: Telecommunications - Television Broadcasting - Meteorology - Maritime Communication - Aeronautical Surveillance - Earth Resources Survey.

The frequency bands used in European Scientific satellites scheduled for launch in the present decade are VHF and S band - Telecommand is transmitted in VHF in GEOS (ESA), IUE (joint ESA-NASA)s UK6 (United Kingdom national programme) and in S-band in ISEE-B (ESA-NASA), EXOSAT (ESA), IRAS (Dutch national programme). Telemetry utilizes VHF in UK6 and GEOS and S-band in IUE, ISEE-B, IRAS, EXOSAT. A common feature of the scientific satellites is that, as far as reception and transmission is concerned, there is no separation between mission support data and payload data. A single Telecommunications package is thus used, housekeeping and experiments data being multiplexed either in baseband or at RF.

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[1] The author is with the European Space Agency, Telecomm. Dept. of the European Space Technology Centre, Noordwijk, Netherlands. The paper does not, however, express of necessity, the point of view of the European Space Agency.

The practice in current ESA application projects, most of which use the geostationary orbit, is to use VHF during injection and to shift to the payload frequencies for routine on-station operation; VHF is also used as a back-up. This applies to the maritime satellite MAROTS, which has Telecommand at 11 GHz and Telemetry at 14 GHz. The same frequencies are used in OTS, forerunner of the European Communication Satellite (ECS). The meteorological satellite (METEOSAT) has Telecommand at S-band and Telemetry at L-band during the operational phase.

The choice of mission support frequencies for the European Television Satellite (TVBS) is not frozen at the moment so it can fall either on the operational Ku-band or in some specialized band. As TVBS is likely to become a major user of the geostationary orbit over Europe (up to 10 units foreseen by the end of next decade) the choice above is of great importance.

Even if direct activity in the field of Earth Resources Survey will most likely be limited for the present decade to reception of data from American satellites, considerable work has been done which can bring in mid 80’s to the launch of both active and passive microwave sounders. The high rate payload telemetry is likely to use millimeter waves as assigned by the radio regulations in spite of propagation impairments.

Such frequencies are not suited for Telecommand and Telemetry, thus a specialized band will probably be used.

The existence of a standard solution - independently of the type of mission - for the transmission of Telecommand and Telemetry will be enquired in the paper. The impact of such a solution both on the ground stations and on the satellite will be considered and the preferred approach examined in some detail.

Objectives and structure of the future European Ground Network. A big share of the European satellites makes use of the geostationary orbit. So a prime task of the ground network is to control and monitor geostationary spacecrafts during the transfer orbit, the drift phase and while on-station. Thus a set of injection stations placed around the equator with more or less complete orbit visibility is required. The payload data of the geostationary satellites will be handled by mission dedicated stations.

The injection network, properly complemented by one high latitude station per hemisphere, will also take care of scientific satellites in highly eccentric earth orbits. The payload data from such satellites have usually a rate not higher than 10 Kb/s and can be multiplexed with the housekeeping Telemetry. In this way no mission dedicated station will be required. Should the raw data from some experiment be substantially higher, the best use of the spacecraft power and ground facilities can be achieved by resorting to some amount of on-board processing.

Neither the injection network nor any network of reasonable size can have full time visibility of low earth orbiting satellites, like e.g. required for Earth Exploration. One solution is to resort to a space relay station, which approach has been taken by the USA. An alternative solution is to use on-board storage of the housekeeping data and to dump the memory when in visibility of a station; similarly a set of instructions to be executed via an on board processor can be loaded during the pass. Even if subject to some operational drawbacks such a solution has the advantage of not requiring the moderate gain (10 - 15 dB) steerable antenna which would be necessary in non-trivial cases (bit rates of the order of a few Kb/s) on the spacecraft to point the relay satellite. The cost of such an antenna is estimated to 1 MAU whereas a.20 Mbit bubble memory would cost less than one half. A firm advantage of on board storage is, in addition, that no space relay station is involved. Thus, on a cost basis, for moderate data rate, use of a spaceborn memory is preferred to an orbiting relay station.

With the solution above, the equatorial injection network complemented by one or two polar station, is enabled to cover the requirements for the control and monitoring of low orbiting spacecrafts. Memory dump is the factor which fixes the highest data rate, to be handled by the common network, to 100 ÷ 200 Kb/s. High eccentrical orbits will hardly require more than 10 Kb/s and for application geostationary satellites it is not foreseen to superate 1 Kb/s. Payload data of low orbit application satellites will be dealt with in mission dedicated stations.

The overall ground facilities will consist of 3 elements;

> The ground stations, which can be either multipurpose stations, serving several satellites on a time sharing basis, or mission dedicated stations
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> The network control centre, which assignes any particular task to the most convenient ground station and controls the flow of data between stations and mission control centres
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> A multimission control center, that processes and evaluates data originating from several satellites and sends appropriate commands to them. For the greatest efficiency the multimission control center is collocated with the network control center. Mission dedicated control facilities will also exist; they can be collocated with the network control center or with a mission dedicated ground station.

As far as non dedicated stations are concerned the most precise requirements on their number and location emanate from the geosynchrono orbit. From a bare visibility point of view, it would be sufficient to use three stations for support to all the phases of the geostationary satellites orbit; it is, however, more secure to use a fourth one against the risk that a station breakdown might unduly prolong the transfer orbit. As for the location, one station will be in Kourou, the second one in any European site with a preference for Madrid, the choice for the remaining two sites is possible among Reunion, Singapore, Okinawa, San Marco, Carnarvon, Pretoria,..Visibility is not the only parameter to be taken into account but also political, economical, spectrum availability factors are to be considered.

As mentioned before, the basic network designed to support geosynchronous missions can be used, with the addition of few further stations, to deal also with different types of orbits.

Use of payload frequency bands. It was illustrated before that the European ground network has to support a wide range of missions of different nature. The operational frequency bands assigned to these missions extend from L band into millimeter waves. Three basic solutions can be thought of in an effort to implement a multimission ground network for the control and monitoring of future spacecrafts:

a) Use of a unique dedicated frequency band for any type of mission or of orbit
b) Use the payload frequency band for any type of mission or of orbit
c) Use a dedicated frequency band for non-geosynchronous satellites and during the transfer orbit of geosynchronous ones. During on station operation the latter will use payload frequencies.

The advantages and drawbacks of each solution are in the following examined.

The main points in favour of solution (a) are:

1) It gives the highest degree of standardization and simplicity to the ground stations of the common network. All stations will be alike and equipped with one front end or with front ends of a single type.
2) A standard transponder and antenna can be used in the spacecrafts Separation of the payload hardware from the platform hardware is favoured by such an approach.
3) No interference or sharing problems exist between payload frequency and the mission control band.
4) A frequency band can be found which is near optimum from the point of view of performances.

Against approach (a) is:

1) In mission dedicated stations it could be desirable to share the operational hardware and the control hardware, Solution (a), on the contrary, requires a separate front end for Telecommand and Telemetry operation.
2) Some extra weight has to be carried by the spacecraft because only limited sharing is possible of the payload hardware.
3) Operational spacecrafts working in the dedicated frequency band would unduly crowd the band which could be - because of its high performances - reserved to critical phases (injection e.g.) or to more demanding missions like scientific satellites in high eccentrical orbits. Such satellites in fact, in addition to the greater range, will have a higher bit rate than application ones due to multiplexing, suggested by economy in the ground stations, of housekeeping and experiments telemetry.

Advantages of approach (b) are:

1) Mission dedicated stations could be simplified by sharing the operational and the control hardware.
2) At spacecraft level, if one renounces to the advantages of separating the payload hardware from the support hardware, some weight and cost saving can be achieved. This does not however apply to antennas because the coverage required during the transfer orbit for Telecommand and Telemetry is not compatible with the requisite of a high gain antenna from the operational payload; thus two antennas would anyway be necessary.
3) There is no need for any frequency band other than those required by the operational mission.

The main drawbacks of (b) are:

1) A multiple set of ground stations, or at least a multiple set of different front ends at each station of the common network is required for each type of mission.
2) Standardization of the on board hardware is very difficult to be achieved.
3) Interference and frequency sharing problems between payload and support dedicated Telecommunications functions are to be considered.
4) The minimum requirements of Telecommand and Telemetry cannot be met in some operational frequency bands (like the 20 GHz band for Earth Exploration) during the transfer orbit. In this phase the spacecraft antenna is bound to be low - or negative - gain due to coverage requirements.

Solution (c) has the following advantages:

1) As far as ground stations are concerned, option (c) has both the advantages of (a) and (b). Ground stations belonging to the common network will use only one type of front end. Mission dedicated stations are not bound to use additional front ends for Telecommand and Telemetry.
2) The dedicated high performance frequency band is used only during critical phases or for the most demanding missions and is left available during routine operation of application geostationary satellites.
3) This solution follows the line pursued up to now in ESA projects and guarantees continuity in the design approach.

Disadvantages of (c) are:

1) It entails the highest degree of complication for the spacecraft which has to carry the hardware related to two frequency bands.
2) Interference problems between payload data and support data may arise in the operational phase.
3) If it is desired to deal with Telecommand and Telemetry in the stations of the common network during the operational phase, separate front ends are to be used at the payload frequencies.

In the course of the discussion a few elements have been individualised on which to base the choice among the three solutions. Shortly, the factors to be weighed are.

introduction of multiple front ends in the ground stations of the common network against possible introduction of an additional front end in mission dedicated ground stations.

separation of the payload hardware from the support hardware and possibility of using a standard transponder and antenna, against some weight reduction in the satellite.

capability of meeting the requirements in terms of spacecraft range and of bit rate

utilization of the radio spectrum

Some basic cost and complexity considerations bring to the conclusion that the introduction of multiple front ends is such a heavy burden as to discourage use of solution (b) for the multimission oriented European network. The introduction of one additional front end at the Telemetry and Telecommand dedicated frequency band is not considered to have a big impact in the economy of the mission dedicated ground stations. Further, access from the latter to the spacecraft platform is an optional feature. Thus, from the point of view of the ground stations complexity, even if solution (c) is preferred no strong objections exist against solution (a), while solution (b) is rejected.

For reasons of operational reliability, sub-system reliability, subsystem cost and to avoid program problems due to an interaction between the payload and the support subsystems, an independent subsystem for Telecommand and Telemetry is strongly preferred. This allows the use of a standard transponder and antenna for any type of mission. A strong point is in this way made in favour of solution (a) which overcomes the modest weight advantage of solution (b). From the on-board point of view, solution (c) is the worst one, because the support hardware has to be, at least partially, duplicated.

In the higher portion of radio spectrum the link budget is affected both from physical parameters (rain and water vapour absorption) and hardware constraints (difficulties in the generation of the RF power and scarce availability of low noise devices). This is a great handicap for solution (b); the impact on solution (c) is less because in the operational phase a directional antenna can be used on the spacecraft. Solution (a), on the contrary, allows the optimization of the link budget by a proper choice of the frequency band, common to all missions, to be used for Telecommand and Telemetry.

From the point of view of spectrum utilization solutions (b) and (c) are undoubtedly better than (a) which can suffer from crowding of the dedicated frequency band. This is not however an actual danger: up to 300 satellites can be supported in an arc of geostationary orbit 30 degrees wide using only 10 MHz of the S band; this applies for Telemetry which is more frequency demanding than Telecommand.

The above figure was computed in the assumptions of a 400 KHz channel width (compatible with a frequency stability of 10^{-5}, with the maximum Doppler shift, with a major ranging tone of 100 KHz and with bit rates up to 50 Kb/s), of a ground station antenna of 9m. in diameter, and of an angular separation between satellites of twice the Wound antenna beam width.

On the basis of the foregoing discussion, it is concluded that it is convenient to use only one dedicated frequency band for the control and monitoring of all spacecraft it any phase of the mission. A suboptimum solution is to use still a common band but with the exception of on-station operation of geosynchronous satellites for which the payload band can be shared.

Choice of the frequency band. In order to answer the question of which band is most suitable as the common band, both technical and frequency regulatory factors must be taken into account.

As already pointed out, technical considerations discourage the use of frequencies higher than 5 or 6 GHz. Problems related to the less favourable physical environment and to the availability of suitable hardware, both for the spacecraft and for the ground stations, were already mentioned; the difficulties increase with increasing frequency. It is worth to add that the beam width tends to become too narrow and the accuracy required in the manufacture of the ground antennas too high.

The Radio Regulations of the “International Telecommunications Union” (ITU) make a distinction between “Space Operation” and “Space Research” services. The bands of interest for the applications being considered are:

Space Research

- 136 - 137 MHz (Downlink)
- 148 - 149.9 MHz (Uplink)
- 2025 - 2120 MHz (Uplink)
- 2200 - 2300 MHz (Downlink)

Space Operation

- 137 - 138 MHz (Downlink)
- 148 - 149.9 MHz (Uplink)
- 1427 - 1429 MHz (Uplink)
- 1525 - 1535 MHz (Downlink)

The bands 2025 - 2110 MHz and 2200 - 2290 MHz are not allowed for use in Europe with the exception of Spain. Use of the 148 - 149.9 MHz band is subject to agreement with interested administrations and results difficult in numerous areas.

Thus, basically the selection is among VHF, L-band and S-band as the Telecommand and Telemetry frequency band, with or - preferably - without the option to shift to the payload frequencies during routine operation of geosynchronous application satellites.

The following factors are in favour of VHF:

There is a set of European stations operating in the band

The spacecraft transponder hardware is the cheapest, the lightest and no development effort is necessary.

For small and simple spacecrafts the VHF antenna is very simple and cheap. A basically omnidirectional coverage is possible. It is. however, seldom necessary.

The first generation of geostationary satellites is based on VHF injection. Continuity of the design would be safeguarded.

Disadvantages of VHF are:

Even if the requirements of the geostationary orbit can be met in VHF, performances are not sufficient for the most demanding missions. This is due to the high sky noise temperature (1500°K typical) to the moderate gain achievable with VHF ground antennas, to the effect of the ionosphere on the rotation of the plane of polarisation (Faraday rotation) and on the propagation delay (inaccurate ranging) which is maximum in VHF.

The control of the antenna pattern in large spacecrafts becomes critical. A case by case design and testing is necessary, to be repeated if during the development of the spacecraft modifications in the structure become necessary.

The channel width in VHF (30 KHz) and the limited width of the whole band (two MHz in the optimistic hypothesis that ITU will agree on the extension of the 136-137 MHz band to Space operation) limit the number of simultaneous satellites that can be supported and originate difficulties for high bit rates (memory dump). Little benefit can be expected from the angular separation of the satellites due to the wide beam width of the ground antennas.

A difficult situation already exists for the sharing of the uplink.

NASA schedules to close its VHF stations in Spring 1978. Thus in the near future no support or backup from NASA can be expected.

CCIR recommendations are likely to limit use of frequencies for Telecommand and Telemetry to the range 1 - 20 GHz, which would ease the World Administrative Radio Conference (WARC) in 1979 to decide to abandon the Space operation part of the band at least.

Other users of the VHF band are exercising pressure on space services to leave the band.

Many scientific satellites are joint NASA-ESA projects. At least for these, S band support would be needed which, considering also the high performance potential of

S band, may end in a network using two frequency bands (VHF + S-band). The majority of European scientific satellites under development use S-band as well.

The main advantages of S-band are:

Its performances are near optimum both from a physical and hardware point of view.
As the spacecraft is several wavelengths in dimension, a certain protection against the details of the structure is available in the antenna design, which means that some amount of antenna standardization is possible. Further, there is some scope in pattern and gain control, thus an on-board antenna gain up to 0 dBi (to be compared with a figure of -6 to -10 dBi in VHF) can be achieved by suitable restriction of the coverage to the angle of interest (±30° to ±60° from the spacecraft equator or cardioid coverage).

Only one frequency is needed to cover both scientific and application satellites.

Spaceborne and ground equipments are rather readily available.

NASA compatibility is possible for support and backup.

The disadvantages of the use of S-band as a common band for Telecommand and Telemetry are:

In the ITU Radio Regulations, provisions should be made for use of the band for “Space Operation” in addition to the present use for “Space Research”. Such a change might encounter heavy opposition.

Agreement is to be reached with NASA which is the major user of the band. No great difficulties are however foreseen.

Some projects under development should change from VHF to S band design for second generation spacecrafts.

Some effort is needed in the refinement of the design of a European S-band transponder having standardization and state of art performances as a goal. The transponder will in any case be more expensive than a VHF one.

Advantages of L band are:

Optimum performances as for S-band.

Same comments as for S-band apply to the spacecraft antenna design.

Spaceborn equipments have been developed for use in Marots and Meteosat.

No regulations problems exist for use of L band frequencies and they are readily available on many sites in Europe and around the world. Drawbacks of the use of L-band are:

Still two bands have to be used: one (L-band) for support to application missions and a second one (S-band) for scientific satellites. The inconvenience is however, less serious than for VHF, because, due to the relative vicinity of the two bands in the radio spectrum, a significant part of the ground equipment can be shared.

Europe would be practically alone in the world as a user of L band for Telecommand and Telemetry. No great external support can therefore be expected.

Some development effort is necessary for the realization of an L-band transponder which will, in any case, be more expensive than a VHF transponder.

Some current projects have to shift from VHF to L band for second generation spacecrafts.

As a result of the above considerations, S-band is the major candidate as a common band for the control and monitoring of future spacecrafts, L-band will be used in case frequency regulation problems could not be solved, existing VHF facilities will be kept operational for a few years to support current programmes based on VHF injection.

Conclusions. Two main conclusions were reached during the discussions above.

The first one is that a specialized frequency band should be dedicated to the control and monitoring of future European satellites, regardless of the type of mission and in any phase of the orbit. As an option, which is not however encouraged, the possibility to shift from the dedicated band to the payload band is considered for the routine operation of geosynchronous application satellites.

The second conclusion concerns the actual choice of the common frequency band. A strong preference was shown in the paper for widespread use of S-band. The solution is, however dependent on a positive outcome of frequency regulation problems. The back-up is to use S-band for scientific satellites and L-band for operational missions, which solution was however shown to be subject to some drawbacks.

Recommendations in line with these conclusions will be shortly issued to ESA responsible bodies as a result of a comprehensive study to which the author is participating.

What is the likelihood that these recommendations are followed? It is the author’s opinion that use of a specialized band is not subject to controversy because it is in line with current practice; a greater stress is however likely to be placed on the option of using payload frequencies on-station, which could be selected in the end.

Some resistance can be expected from the project groups to abandon VHF. But, if our vision of the frequency regulatory problems is correct, they will finally accept this solution specially if faced with realization problems of VHF antennas for bigger spacecrafts.

As a support to the discussion on the trade-off some points were covered which may be valuable in themselves. The main ones are reminded in the following.

> Housekeeping data are multiplexed with payload data in scientific satellites.
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> Four stations will cover all the requirements of the geostationary orbit. Properly complemented such stations can support other mission types as well.
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> The maximum expected Telemetry bit rates are 1 Kb/s for application satellites, 10 Kb/s for scientific satellites, 100 - 200 Kb/s for memory dump of housekeeping data from Earth Exploration satellites.
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> For highly eccentrical orbits, on-board pre-processing is preferred to an increase in the bit rate.
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> For low altitude satellites on-board storage is preferred to the use of space relay stations.
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> A centralization of the network control center and the multimission control center is advised.
>
> The support communication hardware should be kept as separate as possible from the payload hardware in the spacecraft .
>
> An onmidirectional pattern for the satellite antenna is seldon necessary.

Standardization of a transponder for Telecommand, Telemetry (and Ranging) should be pursued.

At S-band the channel width required for housekeeping Telemetry is of the order of 400 KHz including the effect of Doppler drift and carrier instability.

At S-band up to 300 missions can be implemented sharing a bandwidth of 10 MHz and an arc of 30° of the geostationary orbIt.