

Satellite Communications Application to Pacific Countries Above Ku Band

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Abstract

This paper describes an application of satellite communications above the Ku band to the Pacific region, focusing on: (i) Lightsat system and (ii) A high capacity satellite system. A small geostationary satellite system using Ku band for the Federated States of Micronesia is shown as an example. A concept of multi-giga-bits/second high capacity communications system using two satellites in the Ka band is described. This paper also mentions that the onboard bit-by-bit processing is very useful in the low link margin environment due to rain attenuation. These topics were obtained by the Asia Pacific Telecommunications Study granted by NASA (NAGW-1105) conducted by the University of Colorado at Boulder.

1. Introduction

A year long study carried out at the University of Colorado at Boulder, supported by grants from NASA (NAGW-1105) identified a range of exciting new satellite projects for the Pacific region⁽¹⁾⁽²⁾. In this study the Pacific region is defined as covering the "entire" Pacific Rim and all island countries protectorates as well. It can also be called as Asia-Pacific region. The Asia-Pacific region is today at the core of the world economy and is the very promising region in the future.

The first part of this study is the survey of the present status of telecommunications infrastructure in the Asia-Pacific region. The second part of this study gives special attention to the U.S.-Japanese cooperation and in particular to the specific potential satellite projects in the two areas: (i) Lightsats (small satellites) system and (ii) A high capacity satellite system.

These projects are interested to the propagation research in the following two areas: (i) To use the frequency band above Ku band for configuring the small satellite or for establishing the high speed rate communication link. (ii) To apply these higher frequency systems to

the Pacific countries including the tropical region. In addition, this paper mentions also the effect of onboard bit-by-bit processing, since it was clarified by this study that the onboard processing is very useful in the low link margin situation due to rain attenuation in the higher frequency band.

2. Small Geostationary Satellite System

The lightsat means the low cost satellite system. A domestic satellite (DOMSAT) communications system for the Federated States of Micronesia (FSM) represents a good example of a small geostationary satellite application. FSM was selected for this example because of the following factors: (i) The satellite communication is the optimum method to link such a configuration of islands. (ii) A small geostationary satellite is a plausible way to meet their domestic communication needs and to optimize the total cost. (iii) The FSM has a strong wish to build their own domestic communication system. (iv) An agreement to study this system will be obtained from the telecommunications authority of FSM.

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2.1 Satellite System Design

The rough design of the system is shown in the following:

(1) Size of Onboard Antenna and Selection of Frequency Band

The FSM spreads approximately 12 degrees in the latitude and 32 degrees in the longitude. Thus the onboard antenna is required to have the beamwidth of 1 degree by 3 degrees, approximately as shown in Fig. 1. The gain of such an antenna will be about 25 dBi. To obtain such a beam width, the aperture size of C-band antenna is 2 m by 0.8 m. This size is considered to be too big to configure the small satellite. In the Ku band, the antenna aperture will be reduced to be 0.7 m by 0.3 m. This size will be accommodated on the small satellite.

(2) Transmission Rate

The transmission rate of 64 kb/s with bit error rate (BER) of 1×10^{-7} is treated as a basic communication system requirement, considering the utilization of VSAT system existing in the market to reduce the system cost. A 64 kb/s link can accommodate 2-4 voice channels.

(3) Number of Circuits

According to the documents of FSM⁽³⁾, the demand of the number of circuits is forecasted to be 117 in 1991. Therefore 150 circuits are considered in this study for the future demand.

(4) Link Budget

The link budget has been conducted to meet the following requirements: (i) Since the transponder output power of 30 W is available as shown later, the satellite output power per circuit needs to be less than 0.2 W to accommodate 150 circuits. (ii) The link availability of more than 99.6% is preferable. According to the link budget, the communication link can be configured by using VSAT of 2.4 m diameter antenna and 0.7 W output power. The rain attenuation was calculated⁽⁴⁾ by using CCIR Report 564⁽⁵⁾. In this case of 2.4 m VSAT, the satellite power of 0.184 W is required for one circuit (inbound and outbound). Therefore, to accommodate 150 circuit needs the satellite output power of 27.6 W.

(5) Design of Transponder

Table 1 System Parameters of FSM DOMSAT.

| VSAT | VSAT's Output | Sat. Output | No. of Circuit* |
|-------|---------------|-------------|-----------------|
| 2.4 m | 0.700 W | 0.184 W/cct | 163 |
| 1.8 m | 1.243 W | 0.306 W/cct | 98 |

*BER: 1×10^{-7} , Data rate: 64 kb/s, Link Availability: 99.6%.

The TWT amplifier (TWTA) of 30 W linear output power with back-off of 4 dB, whose saturated output power is 75 W, is available. Table 1 shows the system parameters of both 2.4 m and 1.8 m VSAT. The bandwidth of 60 MHz is required, if the maximum number of circuits is 150 and the channel separation is 200 kHz. The weight and consumption power of the transponder are estimated about 8 kg and 123 W, respectively.

(6) Satellite Size

Two cases of the FSM satellite specification (90 kg and 130 kg of weight) are shown in Table 2 as an example. This size of satellite can accommodate 2 transponders (one operational and another redundant). The concept of the FSM DOMSAT is shown in the Fig 1.

2.2 Cost Estimation and Remarks

The very rough total cost is estimated to be \$158.6 M. This cost includes the cost of two satellites and their launches, a satellite control station, hub stations, VSATs and the other facilities for buildings, office equipment, electronics, cable plant, station equipment and other procurement such as vehicles, work equipment, test equipment and engineering, referring the FSM document⁽³⁾. The satellite system has many advantages,

Table 2 Example of FSM Satellite Specification.

| Item | Specifications | |
|------------------------|----------------|--------|
| | Case 1 | Case 2 |
| Diameter (m) | 1.2 | 1.4 |
| Height (m) | 1.2 | 1.4 |
| Solar Array Power* (W) | 226 | 308 |
| Weight in GEO (kg) | 90 | 130 |
| Mission (kg) | 20 | 30 |
| Bus (kg) | 40 | 55 |
| Fuel (15 years) (kg) | 30 | 45 |

*At EOL (End Of Life).

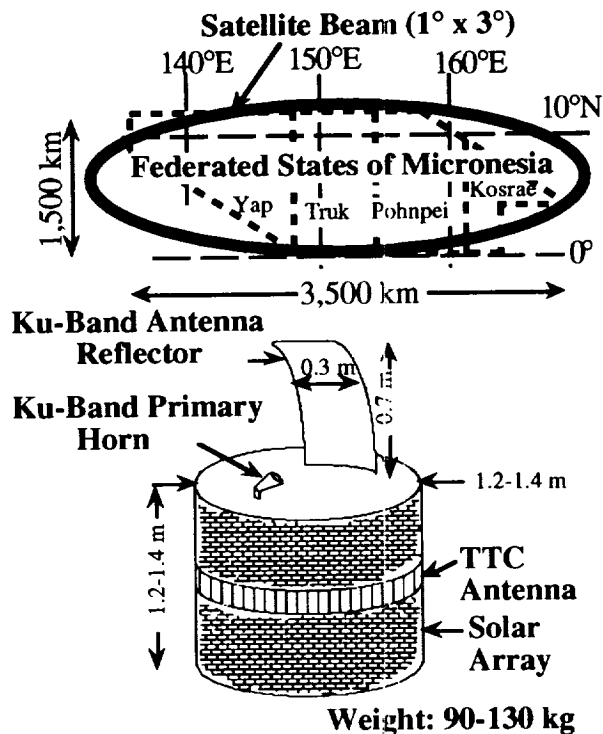


Fig. 1 Concept of FSM DOMSAT.

which can not be measured directly by cost, for example, the flexibility of the system reconfiguration for adding more islands to the system, the improvement of technology skill, and the development of the national identity.

3. Advanced Communication Satellite Concept

3.1 Background

This section addresses a high technology and high performance satellite communications system that attempts to extend the state of the art beyond the ACTS and the ETS-VI or COMETS experimental satellite systems of the U.S. and Japan respectively. We call this satellite as APTS (Advanced Asia-Pacific Telecommunications Satellite). Unlike the lightsats system considered in the previous section, the attempt here to explore super high rate multi-gigabits/second transmission rates for "intelligent" satellite systems of the next century. The 1 Gb/s rate of data transmission for a single data link is considered. This data rate is a good benchmark to support su-

percomputer interconnection, 3-D scientific visualization, 3-D HDTV, desk-top video and other 21st century applications.

The high speed data network using the APTS satellite in the Asia-Pacific region will have the following specific features:

- (i) The 1 Gb/s transmission corresponds to 15,000 equivalent 64 kb/s voice circuits. This is many times the present communication capacity of many countries in the Pacific region. Therefore, the full 1 Gb/s rate capability would apply to only a limited number of high traffic areas in the region. Certainly to link such countries by significantly higher data rates will contribute toward accelerating the further development in the region tremendously. Every country in the region could still have the opportunity to plug into this multi-gigabit satellite at some appropriate data rate using the regional beam.
- (ii) The service area is very large and dispersed in the Pacific region. Then the network completely covered by fiber cables will be unable to be applied for economic reason. The satellite and/or hybrid satellite and fiber technology are very appropriate in this region.
- (iii) However, the need of such super-high data rate is still not well market justified especially in the commercial business field. Thus the development of such a high performance satellite has a technology development aspect.

3.2 Design of APTS Satellite

An advanced communications satellite system envisioned in this study would provide not only 1 Gb/s data rate transmission links to selected cities in Asia-Pacific countries, but would also have a multi-gigabit/second total capacity. It is important, however, to design the satellite as a practical operational prototype that could be placed into commercial service after initial tests and demonstrations are complete. A facility of this complexity, cost, and program di-

mension is too grand of undertaking for simply experimental purposes. By combining U.S. and Japanese resources and obtaining a commitment from commercial sources, a strategy of experimental satellite migrating to operational service could potentially be devised.

The idea is thus to seek aggressively an important new and challenging technology development without undercutting the viability of operational use and recouping of an investment that would at least be many hundreds of millions of dollars. The key issues to be considered with respect to this study option are enumerated below.

(1) Service Area vs. Number of Satellites

The Asia-Pacific region is located over some 200 degrees of longitude from 80 degree East to 80 degree West. This means that any one satellite can not cover the whole region. In addition, the higher frequency band is assumed in order to achieve high data rate transmission. The higher frequency band communication link, however, suffers much more rain attenuation. Since low elevation angles are not desirable, a two satellite system with inter-satellite link is one possible approach. The inter-satellite link will be useful to avoid rain attenuation in the double hop feeder link it slightly increases propagation time. Assuming that the two satellites are located at 150 degree East and 120 degree West, respectively, the distance between two satellite is 90 degrees of longitude and about 59,600 km. The delay time decreases by 42 ms for each way in comparison to the case that double hop interconnection on feeder links are used.

(2) Number of Cities vs. Number of Antenna Beams

Many high data rate beams can be accommodated unless there is a need for close co-location of the beam patterns. Fortunately, the contiguous beam coverage will not be required for the service area in this satellite, since each city is located at sufficient distance apart throughout the vast region of the Asia-Pacific. Therefore the multibeam antenna itself can be designed from a

technical point of view with a high degree of efficiency. Here two 6 beam satellites are examined as an example.

(3) Frequency Band

The service points are located separately from each other and each beam width is very sharply defined in order to obtain the high EIRP. Thus frequency reuse can be established relatively easily. However, since at least 1 GHz bandwidth is needed for what might be called the super beams, the Ka band and/or millimeter wave band will be appropriate. For the inter-satellite communication, the optical wave is the most appropriate to obtain several Gb/s data rate transmission.

(4) Link Parameters

According to the link budget for the Ka band, the onboard antennas would need to be of 220 wave length diameter (3.3 m for 20 GHz and 2.2 m for 30 GHz). This would also require a regenerative type of transponder and earth stations of 5.4 m antenna and a 100 W output power transmitter to accommodate a 1 Gb/s data transmission in the Ka band with a link margin of more than 6 dB and the bit error rate of 1×10^{-7} .

(5) Inter-Satellite Link Capability

The inter-satellite link (ISL) would be optical because of the high bit rates. However, the optical space communication technology itself is still relatively immature and this would be one of the key R&D objectives of the project. In short, much improvement of optical ISL technology will be needed over the next five years to allow the particular project to go forward. For purposes of illustration the 2 Gb/s optical inter-satellite link is considered here.

(6) Configuration of Satellite System

Two satellites, assumed to have almost the same size as ACTS will be connected by optical ISL. It would have 6 super beams, plus one broad coverage beam for regional interconnectivity. The six super beams would be created by two onboard antennas produces the system configuration as shown in Fig. 2. The regional coverage beams are not shown but

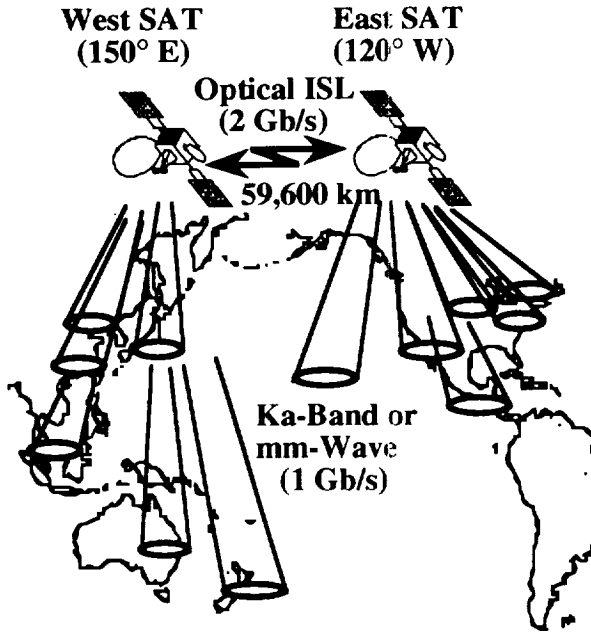


Fig. 2 Concept of APTS.

would be like a modified INTELSAT regional beam. The total bandwidth of this satellite is approximately 10 GHz (6 superbeam satellite-earth links, 1 regional beam and ISL). To organize the satellite as a realizable 2 ton class satellite would be one of the key points of technology development.

(7) Rough Cost Estimation

The cost of this new satellite development can perhaps be estimated from recent experimental projects of the U.S. and Japan. The cost of the APTS satellite (one flight model plus one engineering model for development) is estimated to be around \$400 M, assuming a 20% discount from ACTS. The APTS program as initially conceived would consist of two satellites. It is assumed that the "second" satellite could be developed at about 70% cost of the original satellite. Thus, the total satellite program costs are estimated at \$680 M. The launch cost is estimated at \$130 M per satellite or a total cost of \$260 M including supporting TTC&M costs. These costs should of course be examined in more detail in the final design stage.

4. Onboard Processing Gain

The bit-by-bit or regenerative processing on the satellite transponder is expected to have a gain on its link budget. It does not seem that the discussion has been conducted so far what gain of the onboard processing can be expected if the regenerative type transponder is adopted. This section gives the analytical expression of the onboard processing gain and its maximum gain. The detailed derivation of the equations is given in the Reference (1).

4.1 Onboard Processing Gain in the Up- and Down-Link

(1) Up-link gain for a linear transponder

The onboard processing gain for the up-link, $G|_{r-up}$, is defined to be the ratio of input carrier power of a linear transponder, $C|_{l-up}$, to that of regenerative one, $C|_{r-up}$, to obtain the same link margin:

$$G|_{r-up} = C|_{l-up} / C|_{r-up}.$$

The onboard processing gain for up-link is given by

$$G|_{r-up} = 1 + A,$$

where the noise power spectrum density, N_o , of the linear transponder is the same as that of the regenerative transponder and A is defined the ratio of $C/N_o|_{up}$ to $C/N_o|_{down}$ for the linear and saturated transponder as follows:

$$A = C/N_o|_{up} / C/N_o|_{down}.$$

(2) Up-link gain for a saturated transponder

We can define the onboard processing gain for a saturated transponder to be the $G|_{sr-up}$ like the linear case and it is given by

$$G|_{sr-up} = 1 / (1 - k),$$

where k is defined the ratio of required C/N_o , $C/N_o|_{req}$, to $C/N_o|_{down}$ for the linear and saturated transponder as follows:

$$k = C/N_o|_{req} / C/N_o|_{down}.$$

(3) Down-link gain for a linear and a saturated transponder

The onboard processing gain for the down-link is identical for both the linear transponder and saturated one. The gain, $G|_{down}$, is obtained by

$$G|_{down} = 1 / (1 - k / A).$$

Table 3 Bit-By-Bit Process Gain in the Ka-Band 1 Gb/s Link.*

| Weather Condition | Fine | Rain (up) | Rain (down) |
|----------------------|-------------------|-----------|-------------|
| Up-Link C/No(dBHz) | 106.9 | 99.6 | 106.9 |
| Link Margin(dB) | 14.7** | 0 | 0 |
| Rain Margin(dB) | 14.7** | 0 | 0 |
| Gain(dB) | 0.2 | 0.2 | 8.9 |
| Down-Link C/No(dBHz) | 110.6 | 103.2 | 98.6 |
| Link Margin(dB) | 12.0 ⁺ | 0 | 0 |
| Rain Margin(dB) | 10.0 ⁺ | 0 | 0 |
| Gain(dB) | 0.6 | 12.6 | 0.6 |
| Total Gain(dB) | 0.8 | 12.9 | 9.5 |
| G]max (dB) | 12.9 | | |

*Link Availability is 99.8% in the Tokyo area.

**Including 6 dB power control for rain attenuation compensation. Probability of 0.13%.

⁺Probability of 0.08%.

4.2 Maximum Total Gain

Only the result is shown below.

(1) Linear transponder

The total gain for the linear transponder, G]lr-total, is given by

$$G]lr\text{-total} = A (1 + A) / (A - k) .$$

The maximum gain, G]lr-total max, is given by

$$G]lr\text{-total max} = 1 / \{ k (1 - k) \} .$$

or

$$G]lr\text{-total max} = A_2 (1 + A_2) / (A_2 - k) ,$$

where

$$A_2 = C/No]l\text{-up max} / C/No]down.$$

(2) Saturated transponder

The total gain is given by

$$G]sr\text{-total} = 1 / \{ (1 - k) (1 - k / A) \} .$$

The maximum is obtained by

$$G]sr\text{-total max} = 1 / \{ k (1 - k) \} .$$

4.3 Consideration

The Table 3 shows the onboard bit-by-bit process gain in the APTS link. The bit-by-bit process gain is less than 1 dB in the fine weather. However, the maximum gain of 12.9 dB can be established when we have heavy rain at the up-link with the link attenuation of 14.7 dB. This rain occurs with a probability of 0.13% a year in the Tokyo area. In this case, the down-link gain of onboard processing is 12.6 dB. On the other hand, when we have heavy rain at the down-

link with the link attenuation of 12.0 dB. Such rain occurs with a probability of 0.08% a year. The up-link gain of bit-by-bit processing is 8.9 dB.

This example shows that we can obtain a very high onboard processing gain at the heavy rain condition even for the link with the low onboard processing gain at the fine weather condition.

5. Remarks

In this study, the various satellite communication links were designed by calculating link budgets. In order to estimate the link availability, the rain attenuation was calculated by using the CCIR report. However, the rainfall climatic zone of the CCIR report is very rough and it seems that we have little data in the Pacific region. In that case, we need to have more on-site precipitation data to estimate more actual rain attenuation, since the probability of rain depends strongly on the regional factor. So we should do rain measurement experiment in the Pacific islands countries. These are the future research items for the propagation field research.

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