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Future Mobile Satellite Communication Concepts at 20/30 GHz

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ABSTRACT

The outline design of a system using ultra small earth stations (picoterminals) for data traffic at 20/30 GHz is discussed. The picoterminals would be battery powered, have an RF transmitter power of 0.5 W, use a 10 cm square patch antenna and have a receiver G/T of about -8 dB/K. Spread spectrum modulation would be required (due to interference considerations) to allow a telex type data link (< 200 bit/s data rate) from the picoterminal to the hub station of the network and about 40 kbit/s on the outbound path. An Olympus type transponder at 20/30 GHz could maintain several thousand simultaneous picoterminal circuits. The possibility of demonstrating a picoterminal network with voice traffic using Olympus is discussed together with fully mobile systems based on this concept.

INTRODUCTION

Satellite-communications system at 20/30 GHz offer the exciting possibility of ultra small pocket size earth stations. Microterminals or VSAT (very small aperture terminals) have been established for some years in the 4/6 and 12/14 GHz frequency bands. However, these systems are fixed and cannot be considered to be either portable or easily transported. This paper summarises certain aspects of an ESTEC sponsored study (1) concerned with ultra small satellite terminals at 20/30 GHz, and makes some projections for future mobile systems for these frequencies.

One of the options identified in the ESA study, which might be considered to be portable rather than mobile, was a very small "picoterminal" with antenna sizes of about 10 cm square and beam widths near 10 degrees. Practical portable earth stations, the size of a thick paperback book are now technically possible through developments in VLSI circuits and MMIC technologies. Networks with several thousand simultaneous picoterminal circuits could be supported by the Olympus transponder, albeit with very low data rates for each picoterminal.

A picoterminal network could offer an alternative to the land mobile satellite systems now being considered at L-Band (1.5 GHz). The provision of 2 GHz bandwidth at 20/30 GHz could support a very much larger user community and offer the cost effectiveness of volume production.

THE PICOTERMINAL CONCEPT

The picoterminal concept (Figure 1) was conceived as a purely portable earth station, about the size of a thick paperback book (i.e. 10 cm by 20 cm and some 3-4 cm thick) for telex type data traffic.

These picoterminals would be part of an overall network controlled through a central hub station. However interference from satellites operating in adjacent orbit slots (2 degree spacing) automatically imposes some anti-jam modulation scheme.

Data rates are necessarily low, through power constraints both at the picoterminal and on the satellite. In the immediate future, commercial picoterminal systems would be confined to low data rate telex type messages of up to 200 bit/s.

The practicalities of producing a 20/30 GHz picoterminal depend very much on the achievable performance from monolithic microwave integrated circuits (MMIC). Power levels of near 1W with efficiencies greater than 5% have been reported in Japan (2). The current state of the art for low noise HEMT and MESFET indicate noise figures near 2 dB for 20 GHz. (3).

A printed array antenna has been suggested for the picoterminal. The feeder losses to the individual patches limit the practical peak gain to near 30 dB.

Propagation constraints at 20/30 GHz can be quite severe. Although a 99% availability would be acceptable for the picoterminal-satellite link, a better availability of 99.8% would be necessary on the hub to satellite section.

In Europe at 30 GHz, 99% availability can be achieved with a 4.3 dB margin whereas 14.5 dB is needed to reach the 99.8% level.

Table 1 summarises the parameters used in the subsequent traffic analysis. All the figures chosen are slightly conservative and already achieved in terms of practical systems.

Table 1

Power delivered to antenna	=	-6 dBW
EIRP	=	19.2 dB
System noise temperature	=	29.4 dBK
Antenna gain (edge of coverage	=	21.7 dB
G/T at 20 GHz	=	-7.7 dB/K
E_b/N_o outbound	=	10 dB
E_b/N_o inbound	=	8 dB

Traffic capacity of an Olympus transponder supporting a picoterminal network

The purpose of the calculation is to determine the maximum traffic capacity, which the transponder can support. The 20/30 GHz Olympus transponder parameters have been used where appropriate.

Outbound link budget. It is assumed that the hub station can always provide sufficient power to drive the transponder to a point representing 4 dB below input saturation. Uplink power control at the hub station is anticipated during fading conditions.

The link budget in Table 2 indicates the increasing traffic capacity which can be supported with reducing transponder gain. Taking the first column (maximum transponder gain) of Table 2 as an example, the values of carrier/noise temperature for the uplink $(C/T)_{up}$ and intermodulation $(C/T)_i$ are indicated.

This level of input signal produces an EIRP 48.1 dBW on the downlink (20 GHz) at the edge of coverage. Using the 99% case (i.e. 2.7 dB rain attenuation), the C/N_o achieved at the picoterminal receiver is 56.2 dBHz. Thus a data rate of about 42 Kbit/s can be supported at the highest gain setting with an E_b/N_o = 10 dB.

Some form of spread spectrum modulation is essential to provide protection against interference from similar systems in adjacent orbits.

If the bit rates supported in Table 2 are halved, then the channel will maintain the same equivalent E_b/N_o when the level of interference (I_o) equals the noise level (N_o). Then the relative total level of the interfering signals determines the minimum spreading chip rate. It can be shown that chip rates of 3, 4.6 and 5.4 Mcps, are required to maintain data rates of 21, 31 and 37 kbps on the outbound path in the presence of interference from similar networks in adjacent orbit slots.

Table 2

Outbound Capacity from Single Hub

Input power for saturation	-114.0	-111.0	-108.0	dBW
(C/T)up	-152.6	-147.9	-144.2	dBW/K
(C/T)i (inter modulation)	-151.4	-149.7	-149.0	dBW/K
Signal eirp (EOC)	48.1	49.8	50.5	dBW
Free space loss	-210.0	-210.0	-210.0	dB
Atmospheric loss (99%)	-2.7	-2.7	-2.7	dB
Picoterminal G/T	-7.7	-7.7	-7.7	dB/K
(C/T)dn	-172.3	-170.6	-169.9	dBW/K
(C/T)tot	-172.4	-170.7	-170.0	dBW/K
(C/No)	56.2	57.9	58.6	dBHz
Data rate	46.2	47.9	48.6	dBHz
Data rate	42.2	62.3	73.3	Kbps

Inbound traffic capacity. A similar calculation can be performed to derive the inbound path capacity. However some basic differences should be emphasised. The picoterminal will transmit in the presence of many other simultaneous transmissions. A realistic case assumes that the particular picoterminal is both faded by 4.3 dB and mispointed, whereas all the other systems are unfaded and on boresight. Even with this worst case and the down link to the hub station faded by 7.4 dB, the full transponder can support 1230, 3670 and 8540 simultaneous picoterminal transmissions at data rates of 440, 297 and 180 bps respectively, when received by a hub station of similar G/T to TDS-6. (Transponder gain settings are identical to those of Table 2). It is again necessary to use spread spectrum to overcome the adverse interference from other picoterminal networks, which could produce an interference level 5.4 dB higher than the total power of networks under consideration. Chip rates of 20.4, 40.7 and 58.9 Mcps are necessary to maintain individual picoterminal data rates in the region of 220, 150 and 90 bps respectively. However the combined effect of other interfering networks also reduces the number of terminals in any one network by a factor of 3.5.

Chip rates in excess of a few Megahertz are undesirable and splitting the 40 MHz into several bands is a practical alternative to reduce the code rates.

In a practical system both the inbound and outbound channel could share the same transponder, although the power sharing would need to be controlled carefully to maintain the correct traffic balance. More details of this picoterminal concept are contained in references 1 and 4.

Voice traffic calculations on Olympus. The above traffic calculations apply to a fully operational system which would have to coexist with other similar systems in adjacent orbits. However for the purposes of demonstration, many of the conservative margins imposed on these calculations could be removed for a pure demonstration exercise.

On the outbound path the Eb/No of 10 dB could be reduced to 7 dB as a low error rate is not necessary for a voice channel. A further gain of 3 dB could be achieved from fairly simple coding techniques.

Further gains could also be achieved by operating only in non fading conditions for demonstration (rainfall only occurs for less than 5% of the time in most of Europe). The margin improves by a further 2.5 dB. The accumulated gain of 8.5 dB on the outbound link budget is equivalent to a factor of just over seven in traffic capacity.

Thus the data rates at the three gain settings increase to about 300, 442 and 520 kbit/s. Even if this data rates is reduced to accommodate the spread spectrum modulation, then the total capacity is more than enough for at least 10 speech channels at 9.6 kbit/s.

Following the same logic and assuming the inbound link budget can be improved by 1) reducing the Eb/No level to 7 dB (1 dB gain), 2) using coding providing a further 3 dB, 3) operating in unfaded condition (3.7 dB), and 4) reducing the pointing misalignment by 1 dB, the overall improvement is then 8.7 dB or a factor of 7.4 in the supported data rate.

A data rate of 3.4 kbit/s is marginal for a speech channel. An increase in the picoterminal EIRP to 0.5 W delivered to the antenna seems desirable to bring the data rate above the 4.8 kbit/s required for a reasonable speech channel.

The demonstration system could be operated using conventional time division multiplexing (TDM) on the outbound path and single channel per carrier (SCPC) on the inbound route. However this would not demonstrate the advantages of spread spectrum random access systems, particularly on the inbound path. If a ten voice-channel system is envisaged on Olympus, using a picoterminal network, then one compromise solution of TDM on the outbound path could be combined with a spread spectrum system for the return signals from the picoterminals to the hub station.

A ten voice channels system would require 96 kbit/s on the outbound path, equivalent to 32% of the transponder capacity. The remaining capacity could be allocated to the inbound link which could support up to 400 channels at 6.6 kbit/s by extrapolation from the previous traffic calculation. If a spreading code modulation system is used, the channel throughput rate reduces. However with only ten channels operating simultaneously and in the absence of interference from other systems, then the reduction in throughput rate is much lower than the 50% calculated above. For instance a processing gain of 25 dB allows ten channels to operate with a reduction in the date rate of ony 14%, ie more than adequate to support a 4.8 kbit voice channel.

These rather tentative calculations suggest that the Olympus satellite could provide a useful demonstration for a voice channel network operated through a number of these very small portable picoterminals.

MOBILE APPLICATIONS AT 20/30 GHz

The above discussion of the picoterminal concept has concentrated on portable rather than mobile applications. To progress the concept to the mobile application requires consideration of a number of new constraints, most of which are related to propagation and antenna aspects of the system.

A truly mobile system should in principle operate with a specified systems performance, anywhere in the coverage area. This requirement is difficult for any mobile satellite system, as propagation constraints are always present. However increasing the frequency of operation of a satellite system from the currently utilized bands around L Band (1.5/1.6 GHz) to 20/30 GHz does not impose insurmountable propagation problems. The building blockage problems only deteriorate marginally. However the problems imposed by vegetation are significantly worse with acceptable transmission through anything more than a small bush being very difficult to accommodate with any realistic link margin (5).

However, the greatly increased rain attenuation in the millimetre bands does not contribute as much to the system outage time as would be expected. Only a 4 dB margin is necessary to provide a 99% service. This availability is much higher than expected from building, terrain and vegetation effects, even at the much lower L-Band frequencies.

Mobile antenna considerations do require a higher level of accuracy than those currently being developed at L-Band. The maximum proposed gain of steerable antennas at L-Band is about 12 dB, producing 3 dB beam widths of about 50°. The antennas proposed for the picoterminal are equivalent beam widths near 10°, ie requiring nearly an order of magnitude increase in the search and tracking system, when compared with the L-Band situation.

It would be a poor engineering compromise to increase the antenna beam width to alleviate these antenna system problems, as the high achievable gain for practical sized antennas is one of the main advantages of 20/30 GHz mobile systems. The incentive should be to reduce the beam width even further by increasing the antenna dimension thus increasing the traffic capacity of the overall system. It is debatable whether the ultimate limitation will be the antenna size which can be readily mounted on a mobile or the constraints imposed on the search and tracking mechanism.

The antenna steering configuration for these millimetric bands will probably follow the trends at lower frequencies, where combinations of patch arrays and electro mechanical steering have been developed for systems which have to accommodate the range of relatively low elevation angles (10° to 50°), associated with geostationary systems.

Although a number of other mobile system problems which arise from doppler shift, intermittant signal blockage and multipath occur, the portable picoterminal concept could be extended to provide conventional mobile services.

NON-GEOSTATIONARY ORBITS

There seems to be an even more over-riding case to investigate non-geostationary orbits for 20/30 GHz than at lower frequencies for certain parts of the world - especially Europe. Firstly the propagation margin for rain could be reduced even further. Typically the rain occurs in the first 3 km of the troposphere. Thus 3 mmh^{-1} of rainfall rate (the level exceeded for 1% of the time) produces an attenuation of less than 0.6 dB at 30 GHz on a vertical path. If satellites using the highly elliptical Molniya or Tundra orbits (Figure 2) are considered, then the elevation angle to the satellite is always above 50° for all of Europe. (Figure 3). The rain attenuation is still less than 2 dB and many of the building, terrain and vegetation attenuation problems disappear as a result of the much higher elevation.

The antenna tracking problem on the mobile is also reduced as a vertically pointing antenna only needs to track about ± 4 beam widths to cover the complete range of situations possible. With this configuration (ie the near zenith inclined orbit system) the hand held portable becomes a practical possiblity. For a geostationary system using a high gain antenna, it is necessary to have a sophisticated phased array tracking antenna and to know approximately where the satellite is situated to avoid blockage from both the operator and buildings. For the inclined orbit system however, the operator only needs to point the antenna vertically upwards. A simpler tracking system or a wider beam antenna would lock onto the satellite transmission much more easily.

CONCLUSION

The concept of the picoterminal network operating at 20/30 GHz through an Olympus type transponder has been demonstrated to support several thousand low data rate channels for telex traffic in an operational environment. This concept of the very small portable earth terminal can also be extended to demonstrate a voice traffic system, again through an Olympus type transponder. However an operational system would need to be supported through a much more powerful satellite such as ACTS (6). The portable concept can be extended to fully mobile applications. However geostationary orbit configurations are a poor compromise with inclined orbit systems offering even more advantages for the 20/30 GHz mobile satellite systems than their lower frequency counterparts.

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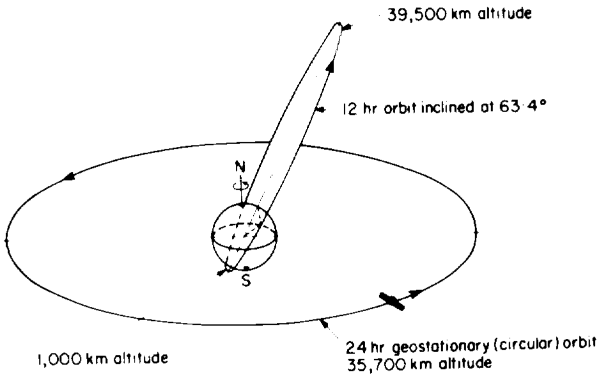

Molniya (12 hour) and Geostationary orbits

Figure 2

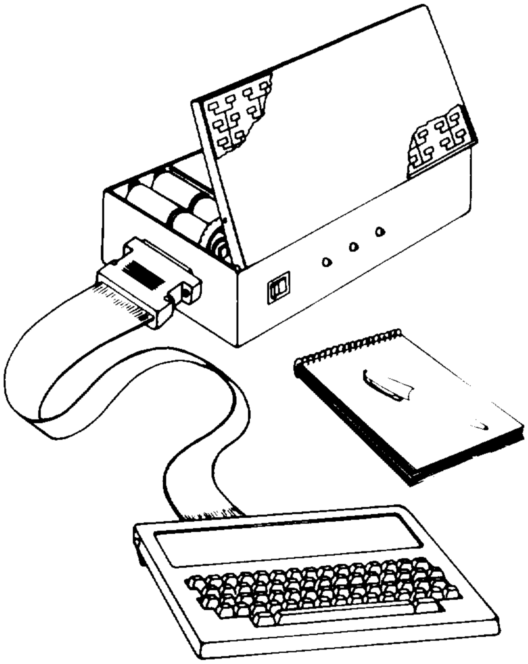

Figure 1: Picoterminal

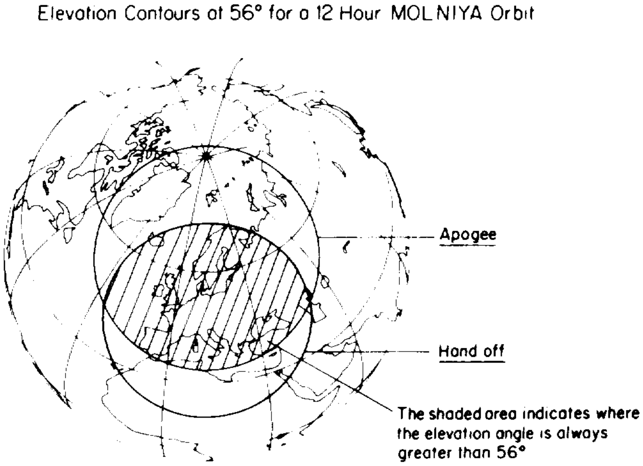

Figure 3