A satellite operated by the International Telecommunications Satellite Organization (INTELSAT) and located at 307° East longitude (53° West) provides new and unique capabilities for the coordination of time scales in North America and Europe using the two-way technique. A network of coordinated clocks using small satellite earth stations collocated with the time scales is possible. Antennas as small as 1.8 m at K-band and 3 m at C-band transmitting powers of less than 1 W will provide signals with timing jitters of less than 1 ns using the MITREX spread spectrum modems.

The technical details of the satellite and requirements on satellite earth stations are given. The resources required for a regular operational international time transfer service is analyzed with respect to the existing international digital service offerings of the INTELSAT Business Service (IBS) and INTELENT. Coverage areas, typical link budgets, and a summary of previous domestic and international work using this technique are provided. Administrative procedures for gaining access to the space segment are outlined. Contact information for local INTELSAT signatories is listed. A typical satellite earth station with time transfer capability is described in some detail.

Spread Spectrum Time Transfer via INTELSAT

The microwave time and ranging experiments (MITREX) modem is an efficient device for time transfer via satellite using spread spectrum techniques. International time transfer using satellite spread spectrum techniques regularly will probably require the use of an INTELSAT space segment. There are no substantial technical problems in such use. However, it is necessary to identify the operational issues of using this system in the INTELSAT environment. This paper describes the INTELSAT service compatible with spread spectrum time transfer and suggests how such a service could be implemented.

INTELSAT, the International Telecommunications Satellite Organization, with headquarters in Washington, D.C., is an international cooperative of 117 member nations that owns and operates the global commercial communications satellite system used by countries around the world for international communications and by 35 countries for domestic communications. A fundamental characteristic of the system, from the point of view of time transfer is that access to the INTELSAT space segment is controlled by various national entities, usually the members of INTELSAT. These entities are responsible for the operation of earth stations accessing INTELSAT space segment. In many cases, these entities, the posts, telephones and telegraphs (PFT’s), are part of their national government or are charted by their governments to provide access to INTELSAT. The earth stations may be owned directly by the entities, by common carriers or by the end users, depending on national policy. INTELSAT operates only the space segment and has no direct role in the operation of the ground segment. Thus, time transfer users will need to arrange with their national entities for earth station operation and for the right to use INTELSAT space segment. Appendix I of this paper contains contact points for these entities in North America and Europe.

Services

Two specialized INTELSAT services are intended for digital links to small earth stations. INTELENT in particular, has enough flexibility in its technical description to allow the operation of a spread spectrum time transfer link.

INTELENT

INTELENT was designed to facilitate the operation of very small earth stations in one-way data broadcasting and two-way low speed data transfers. Spread spectrum operation is allowed, along with conventional BFSK or QPSK modulation. Operation under the INTELENT service description is specifically authorized for very small antennas.

Space segment is leased in "bulk" under the INTELENT service. This offering is defined in terms of specific transponder bandwidths with a corresponding allocation of power. Any required bandwidth may be used, with the resources scaled from the defined allocation. For example, at K-band, a lease of 1 MHz capacity would provide 22 dBW of transponder power. A lease of 2.25 MHz would provide 25.52 dBW. In general, the ratio of power to bandwidth is higher (excess power) than is needed for a single spread spectrum time transfer link. Both full time and occasional use service, with a minimum of 30 minutes per period, is available.

We use trade names and company names to specify the experimental procedure adequately and do not imply endorsement by the National Institute of Standards and Technology.

*Contribution of the U.S. Government; not subject to copyright.
Listed below are the basic lease powers, referenced to a 1 MHz bandwidth, available on the INTELSAT V A-F(13) spacecraft.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>dBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>C-Band</td>
<td>3.5</td>
</tr>
<tr>
<td>Hebi</td>
<td>C-Band</td>
<td>4.5</td>
</tr>
<tr>
<td>Zone</td>
<td>C-Band</td>
<td>4.5</td>
</tr>
<tr>
<td>West spot</td>
<td>K-Band</td>
<td>13.5</td>
</tr>
<tr>
<td>East spot</td>
<td>K-Band</td>
<td>16.0</td>
</tr>
</tbody>
</table>

**INTELSAT Business Service**

Space segment for digital communications links can also be obtained under the INTELSAT Business Service (IBS) tariff. In this service the power and bandwidth supplied to each channel are defined in terms of reference links between standard sized earth stations. The reference link assumes conventional QPSK data transmission with either rate 3/4 or rate 1/2 forward error correction (FEC).

Sufficient power is available to provide better than $10^4$ bit error rate performance under clear sky conditions. It is available under a full-time, part-time (scheduled at least 1 hour per day, 7 days per week), or occasional-use tariff. While the spread spectrum nature of the MITREX modem is outside the IBS technical description, the IBS service should be considered when it is necessary to provide communication links between standards sites.

On most transponders where IBS is used, INTELSAT has reserved occasional use capacity. This bandwidth could be used to accommodate the MITREX modem operating under the INTELSAT service as described below.

**Operational Matters**

In all three ocean regions there are satellites with capacity reserved for occasional use. The reserved bandwidth is 3.137 MHz wide, sufficient for a 2.048 Mb/s IBS carrier. These occasional use channels clearly would accommodate a spread spectrum link if the transmit spectrum were restricted by additional filtering. In the full-connectivity transponders, described below, the reserved capacity is in the form of two adjacent occasional-use channels, providing a bandwidth of 6.345 MHz. The operating frequencies for the occasional use channels are listed in Appendix 2.

**Transponder Configurations**

Most of the Europe-North America IBS traffic is carried on the INTELSAT V A-F(13) located at 307° East. The following configurations of transponders are currently available:

- East K-band spot to West K-band spot
- West K-band spot to East K-band spot
- East K-band spot to West C-band hemi
- West C-band hemi to East K-band spot
- West K-band spot to East C-band hemi
- East C-band hemi to East K-band spot
- West C-band zone to East C-band zone
- East C-band zone to West C-band zone
- West C-band hemi to West C-band hemi
- East C-band zone to East C-band zone

The full-connectivity transponder configuration provides the most flexible environment for time transfer links. This consists of a set of four transponders, interconnected at the satellite so that a signal received on any of the four uplink beams is retransmitted on all four downlink beams simultaneously. Two of the beams operate at C-band. These are the West Hem and the East Hem. The coverage of these spacecraft antennas is shown in Figure 1. Interconnected with these two C-band hemi beams are two K-band beams. The K-band West spot covers the United States and southern Canada, as can be seen Figure 2. The East K-band beam, Figure 3, covers western Europe.

Full-connectivity operation can be used with spread spectrum code division multiple access (CDMA) to allow several time transfer links to be established simultaneously on the same frequency, with all carriers visible to each user. This means that in a two-station, two-way transfer, it is possible for each site to monitor its own signal while receiving from the remote site.

Additional capacity in the form of East spot-West spot K-band capacity is available at the 325.3° East and 335.5° East locations. C-band capacity is assigned on the 325.5, 335.5 and 341.5° East locations serving the Atlantic Ocean region, on the Indian Ocean satellite at 63° East and in the Pacific region at 174 and 180 degrees East. K-band capacity is also available in the Pacific Ocean region between Korea and Japan and the West coast of the United States.

**Link Budgets for MITREX**

The link budgets in Table 1 show the required power for a time transfer link operating in the full-connectivity transponder. The transmitted power has been set to produce at least 54 dBHz to a small K-band (1.8 m) station. This same power will also be sufficient for use with a C-band 4.5 m antenna. These link budgets show both the uplink and the downlink calculations for each of the four full-connectivity transponders, West spot, East spot, West hemi and East hemi. In the full-connectivity configuration, an uplink will produce different downlink powers in the four downlink beams, depending on the individual IOT characteristics and satellite antenna gains. The bottom section recalculates what the spread spectrum signal would look like at the largest earth stations using the transponder, standard C station K-band, and standard A at C-band, on a spectrum analyzer. This indicates what the interference potential of such a carrier would be to other users operating links in these transponders. Even to such large stations, the spread spectrum operation appears as a very low level carrier. At the most visible location, a standard C-band receiving each station located in the West spot downlink, the received noise floor will be increased by 6.4 dB.

With the assumption of the use of 1.8 m K-band antennas and 4.5 m C-band antennas, the links can be summarized as follows:
Figure 1. INTELSAT WA(IBS) Interconnections from 307° East

Figure 2. INTELSAT WA(IBS) West Spot Coverage from 307° East

Figure 3. INTELSAT WA(IBS) East Spot Coverage from 307° East
### Table 1

<table>
<thead>
<tr>
<th>Symbol Rate</th>
<th>2500.0</th>
<th>Kbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit e.i.r.p.</td>
<td>56.9</td>
<td>45.6</td>
</tr>
<tr>
<td>Tracking error</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>U/L margin</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>U/L path loss</td>
<td>207.3</td>
<td>207.4</td>
</tr>
<tr>
<td>U/L asp. corr.</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Gain 1 [m²]</td>
<td>44.4</td>
<td>44.4</td>
</tr>
<tr>
<td>Operating flux b.c.</td>
<td>-110.4</td>
<td>-119.8</td>
</tr>
<tr>
<td>Sat. flux b.c.</td>
<td>-73.6</td>
<td>-83.0</td>
</tr>
<tr>
<td>Input back-off</td>
<td>-36.8</td>
<td>-36.8</td>
</tr>
<tr>
<td>TVIF I/O</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Output back-off</td>
<td>30.8</td>
<td>30.8</td>
</tr>
<tr>
<td>saturated e.i.r.p.</td>
<td>46.5</td>
<td>46.6</td>
</tr>
<tr>
<td>D/L e.i.r.p. b.c.</td>
<td>15.7</td>
<td>13.8</td>
</tr>
<tr>
<td>D/L e.i.r.p. beam edge</td>
<td>11.7</td>
<td>9.8</td>
</tr>
</tbody>
</table>

**C/T & G/N Calculations:***

- **C/T** Intermod: -136.9
- **C/T** at b.c.: 15.7
- **C/T** at beam edge: 11.7

**Boltzmann's constant:** 1.38 × 10^-23 J/K

**Spectral analyzer (C_e/N_0):** 0.8

**Same links as received at large Standard C and A Earth stations:**

- **C/T** at b.c.: 15.7
- **C/T** at beam edge: 11.7

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**Notes:**

- **C_e/N_0** values are typically used to assess the signal-to-noise ratio for DTH or cable systems.
- **C/T** values are crucial for determining the capacity of a communication link.
- **Boltzmann's constant** is fundamental in thermodynamics, relating energy to temperature.
- **Spectral analyzer** helps in characterizing the signal's power distribution across frequency.
clearly be suitable. Links involving larger stations will need even less transmitting power.

Any earth station classed as a standard INTELSAT antenna must satisfy the sidelobe gain limit described by the expression:

\[ G = 32 - 25 \log \theta, \]

where \( G \) is the gain of the sidelobe envelope relative to an isotropic antenna in the direction of the geostationary orbit and is expressed in dB, and \( \theta \) is the angle in degrees from the axis of the main lobe.

In addition antennas operating at C-band must use circular polarization with a voltage axial ratio that does not exceed 1.09. However C-band antennas with a diameter of 2.5 m or less are only required to have a voltage axial ratio of 1.3. To operate in the IBS service a K-band antenna must have a minimum G/T ratio of 25 dB/K, qualifying as a standard E1. At C-band the G/T requirement is 22.7 dB/K and a minimum transmitting gain of 47.7 dB1 to qualify as an F1 standard antenna.

**Implementation**

INTELSAT has always been willing to support innovative uses of satellite technology by granting free use of space segment for tests and demonstrations. A request for free use must be submitted through the national signatory for each station involved. The technical approval process for a test or demonstration has two parts:

1. Initially, the earth stations involved must be approved. Small stations not having the minimum G/T values (25 dB/K at K-band, 22.7 dB/K at C-Band) for IBS stations, would have to qualify under the standard G specification.

2. A transmission plan for the proposed experiment will have to be examined to see whether what is proposed will work with the resources requested and, finally, whether the proposed transmissions may cause harm to other users of the space segment.

After approval, the carrier powers are set up in accordance with a test plan issued by INTELSAT and the experiment will then proceed. At the conclusion of the experiment, the participating Signatories are obligated to submit to INTELSAT a test report on the results. This report will be made available to any interested INTELSAT members.

One objective of such an experiment should be an evaluation of the compatibility of such a service with normal INTELSAT operations, with the view to proposing a tariffed technical description of spread spectrum time transfer. This could then be submitted to the INTELSAT Board of Governors for formal approval as a regular International service with the resources allocated and the consequent tariffs appropriate to the unique demands of spread spectrum time transfer.

Alternatively, commercial service could start immediately under the INTELSAT service definition and tariffs. The occasional-use option would probably satisfy the requirements for periodic coordination links between various national standard labs.
Appendix 1.

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Appendix 2

Occasional Use Frequencies

<table>
<thead>
<tr>
<th>Transponder</th>
<th>Configuration</th>
<th>Uplink</th>
<th>Downlink</th>
</tr>
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<tr>
<td>11/11</td>
<td>WH/WH</td>
<td>5933.7700</td>
<td>3708.7700</td>
</tr>
<tr>
<td>41/41</td>
<td>WZ/WZ</td>
<td>5930.5975</td>
<td>3705.5975</td>
</tr>
<tr>
<td>51/51</td>
<td>EZ/EZ</td>
<td>5930.5975</td>
<td>3705.5975</td>
</tr>
<tr>
<td>42/52</td>
<td>WZ/EZ</td>
<td>6015.5750</td>
<td>3790.5750</td>
</tr>
<tr>
<td>52/53</td>
<td>EZ/WZ</td>
<td>6015.5750</td>
<td>3790.5750</td>
</tr>
<tr>
<td>51/43</td>
<td>EZ/WZ</td>
<td>6095.5975</td>
<td>3870.5975</td>
</tr>
<tr>
<td>13/173</td>
<td>WH/ES</td>
<td>6106.9825</td>
<td>12686.9825</td>
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<tr>
<td>73/13</td>
<td>ES/WH</td>
<td>14176.0425</td>
<td>3876.0425</td>
</tr>
<tr>
<td>23/163</td>
<td>EH/WS</td>
<td>6095.5975</td>
<td>11875.5975</td>
</tr>
<tr>
<td>63/23</td>
<td>WS/WH</td>
<td>14169.0000</td>
<td>3869.0000</td>
</tr>
<tr>
<td>61/171</td>
<td>WS/ES</td>
<td>14058.0000</td>
<td>12563.0000</td>
</tr>
<tr>
<td>71/161</td>
<td>ES/ES</td>
<td>6017.16</td>
<td>3792.16</td>
</tr>
<tr>
<td>12/22/62/72</td>
<td>Full Connectivity</td>
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</tr>
<tr>
<td>162/172</td>
<td>6017.16</td>
<td>3792.16</td>
<td></td>
</tr>
<tr>
<td>14092.16</td>
<td>11797.16 (WS)</td>
<td>12597.16 (ES)</td>
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