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TWO-WAY SATELLITE TIME TRANSFERS BETWEEN AND WITHIN NORTH AMERICA AND EUROPE*

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Abstract

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 INTELNET. 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

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 (PPT's), are part of their national government or are chartered 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 1 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. INTELNET in particular, has enough flexibility in its technical description to allow the operation of a spread spectrum time transfer link.

INTELNET

INTELNET 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 BPSK or QPSK modulation. Operation under the INTELNET service description is specifically authorized for very small antennas.

Space segment is leased in "bulk" under the INTELNET 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.

Listed below are the basic lease powers, referenced to a 1 MHz bandwidth, available on the INTELSAT V-A(F-13) spacecraft.

Global	C-Band	3.5 dBW
Hemi	C-Band	4.5 dBW
Zone	C-Band	4.5 dBW
West spot	K-Band	13.5 dBW
East spot	K-Band	16.0 dBW

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 for a 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 (F.E.C.). Sufficient power is available to provide better than 10^{-8} 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 INTELNET service as described below.

Operational Matters

In all three ocean regions there are satellites with capacity reserved for occasional use. The reserved bandwidth is 3.173 MHz wide, sufficient for a 2.048 Mbits/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 American IBS traffic is carried on the INTELSAT VA(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	West K-band spot
East K-band spot	to	West C-band hemi
West 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

East K-band spot	full-connectivity	East K-band spot
West K-band spot		West K-band spot
East C-band hemi		East C-band hemi
West C-band hemi		West C-band hemi

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 Hemi and the East Hemi. The coverages 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 325.5° 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 or 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 dB-Hz 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 TWT 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 earth 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:

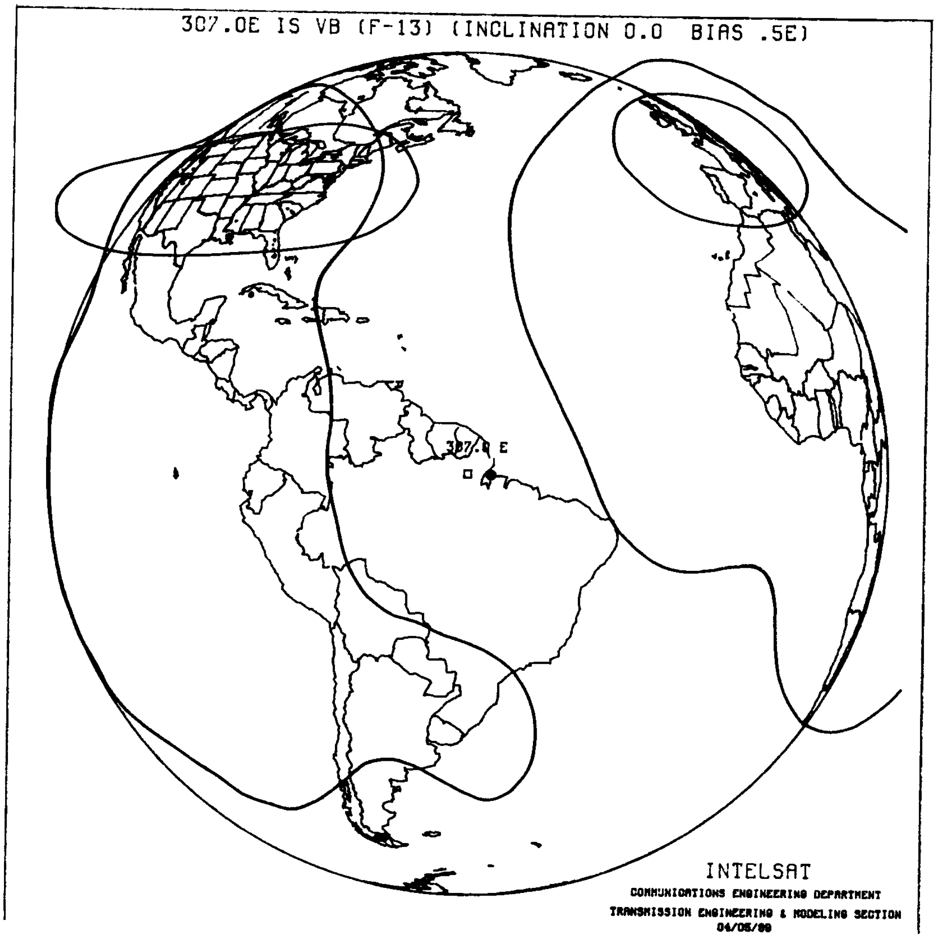

Figure 1. INTELSAT VA(IBS) Interconnections from 307° East

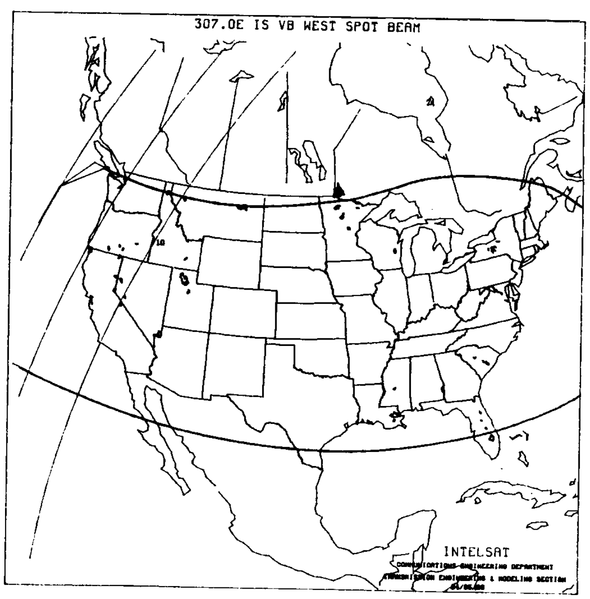

Figure 2. INTELSAT VA(IBS) West Spot Coverage from 307° East

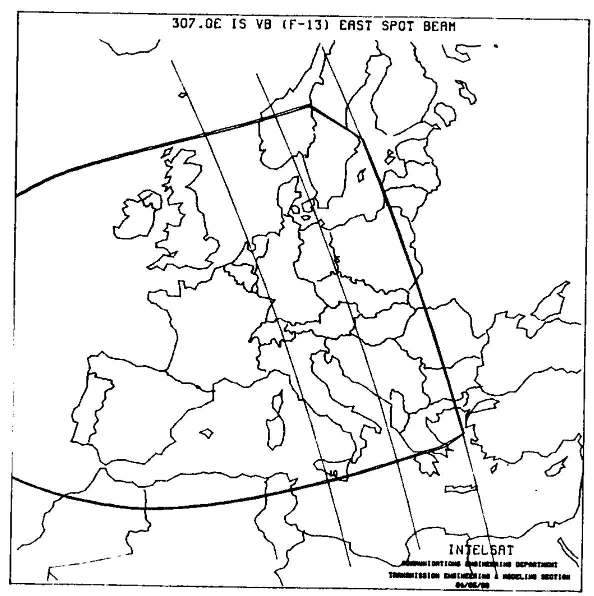

Figure 3. INTELSAT VA(IBS) East Spot Coverage from 307° East

Table 1

Project: MITREX Modem Link
Actual Transponder Operating Values
TX E/S: Std. G RX E/S: Std. G 1.8 m K-band 4.5 m C-band

SATELLITE & LOC. : INTELSAT V-A(F-13) @ 307° EAST
TRANSP.: WS/ES Full-connectivity High Gain
Carrier Type: Time Transfer Spread Spectrum
U/L CARR. FREQ.(MHz): 14092.16 14092.16 6017.16 6017.16
D/L CARR. FREQ.(MHz): 12597.16 11797.16 3792.16 3792.16

Co-channel Interference X Value (IESS-410 Table 1) 22 dB

Symbol Rate	2500.0	Kbit/s			
	WS/WS	ES/ES	WH/WH	EH/EH	
Transmit e.i.r.p.	54.9	45.6	46.0	45.9	dBW
Tracking error	0.5	0.5	0.5	0.5	dB
U/L margin	0.0	0.0	0.0	0.0	dB
U/L path loss	207.3	207.4	197.7	197.7	dB
U/L asp. corr.	2.0	2.0	2.0	2.0	dB
Gain 1 m^2	44.4	44.4	37.0	37.0	db/m^2
Operating flux b.c.	- 110.4	-119.8	-117.1	-117.2	dBW/m^2
Sat. flux b.c.	-73.6	-83.0	-80.3	-80.4	dBW/m^2
Input back-off	-36.8	-36.8	-36.8	-36.8	dB
TWT I/O	6.0	6.0	4.3	4.3	dB
Output back-off	-30.8	-30.8	-32.5	-32.5	dB
saturated e.i.r.p. b.c.	46.5	44.6	32.4	33.0	dBW
D/L e.i.r.p. b.c.	15.7	13.8	-0.1	0.5	dBW
D/L e.i.r.p. beam edge	11.7	9.8	-4.1	-3.5	dBW

C/T & C/N CALCULATIONS:

Transmit e.i.r.p.	54.9	45.6	46.0	45.9	dBW
Tracking error	0.5	0.5	0.5	0.5	dB
U/L margin	0.0	0.0	0.0	0.0	dB
U/L path loss	207.3	207.4	197.7	197.7	dB
U/L asp. corr.	2.0	2.0	2.0	2.0	dB
Satellite G/T b.c.	-1.9	0.5	-8.7	-8.7	dB/K
$(C/T)_{up}$	-156.8	-163.8	-162.9	-163.0	dBW/K
(C/T) intermod	-136.9	-138.8	-152.7	-152.1	dBW/K
D/L e.i.r.p. at b.c.	15.7	13.8	-0.1	0.5	dBW
Tracking error	0.5	0.5	0.5	0.5	dB
D/L margin	0.0	0.0	0.0	0.0	dB
D/L path loss	205.7	206.5	195.8	196.5	dB
D/L asp. corr.	2.0	2.0	2.0	2.0	dB
E/S G/T	21.0	21.0	22.7	22.7	dB/K
$(C/T)_{dn}$	-171.5	-174.2	-175.7	-175.8	dBW/K
(C/T) Downlink X-pol & ASI	-141.8	-141.8	-141.8	-141.8	dBW/K
$(C/T)_t$ link	-171.7	-174.6	-176.0	-176.1	dBW/K
Boltzmann's const.	-228.6	-228.6	-228.6	-228.6	dBW/Hz-K
C/N_o link	56.9	54.0	52.6	52.5	dB/Hz
Allocated BW	3500.0	3500.0	3500.0	3500.0	kHz
Occupied BW	3000.0	3000.0	3000.0	3000.0	kHz
10 log BW	64.8	64.8	64.8	64.8	dB-Hz
C/N	-7.8	-10.8	-12.1	-12.2	dB
Trans. rate E_b/N_o	-7.1	-10.0	-11.3	-11.4	dB
C_o/N_o	-7.1	-10.0	-11.3	-11.4	dB
Spectrum analyzer $(C_o+N_o)/N_o$	0.8	0.4	0.3	0.3	dB

Same links as received at large Standard C and A earth stations

D/L e.i.r.p. at b.c.	15.7	13.8	-0.1	0.5	dBW
Tracking error	0.5	0.5	0.5	0.5	dB
D/L margin	0.0	0.0	0.0	0.0	dB
D/L path loss	205.7	206.5	195.8	196.5	dB
D/L asp. corr.	2.0	2.0	2.0	2.0	dB
E/S G/T	37.0	37.0	35.0	35.0	dB/K
$(C/T)_{dn}$	-155.5	-158.2	-163.4	-163.5	dBW/K
(C/T) Downlink X-pol & ASI	-141.8	-141.8	-141.8	-141.8	dBW/K
$(C/T)_t$ Link	-159.3	-164.9	-166.4	-166.4	dBW/K
Boltzmann's const.	-228.6	-228.6	-228.6	-228.6	dBW/Hz-K
C/N_o link	69.3	63.7	62.2	62.2	dB/Hz
Allocated BW	3500.0	3500.0	3500.0	3500.0	kHz
Occupied BW	3000.0	3000.0	3000.0	3000.0	kHz
10 log BW	64.8	64.8	64.8	64.8	dB-Hz
C/N	4.5	-1.0	-2.5	-2.6	dB
Trans. rate E_b/N_o	5.3	-0.2	-1.7	-1.8	dB
C_o/N_o	5.3	-0.2	-1.7	-1.8	dB
Spectrum analyzer $(C_o+N_o)/N_o$	6.4	2.9	2.2	2.2	dB

Uplink beam	WS	ES	EH	WH	
Antenna size	1.8	1.8	4.5	4.5	m
Hpa power	7.7	0.9	1.0	1.0	W
Hpa power	8.9	-0.4	0.0	-0.1	dBW
Antenna gain	46.0	46.0	47.7	47.7	dBi
E.I.R.P.	54.9	45.6	47.7	47.6	dBW

Downlink beam	WS	ES	WH	WH	
Beam edge power	11.7	9.8	-4.1	-3.5	dBW
1 MHz lease	13.5	16.0	4.5	4.5	dBW
2 MHz lease	16.5	19.5	7.5	7.5	dBW

MITREX Modem Use

The simplest way to use the MITREX modem on INTELSAT would be to identify a tariffed INTELNET service that provides at least the necessary power and bandwidth. For regular PSK transmissions, the signal bandwidth at the -18 dB points is required to be within the allocated bandwidth. As can be seen in the attached spectrum analyzer plot. Figure 4 shows, the bandwidth of the MITREX modem is 3.5 MHz at the -18 dB point. The 6 dB bandwidth of the MITREX modem output is 2 MHz. It is possible to apply additional filtering to the spread spectrum transmitted signal reducing its -18 dB bandwidth, and thus the nominal tariff. However with the spread spectrum operation at such low levels, the -18 dB bandwidth may not be appropriate for tariffing.

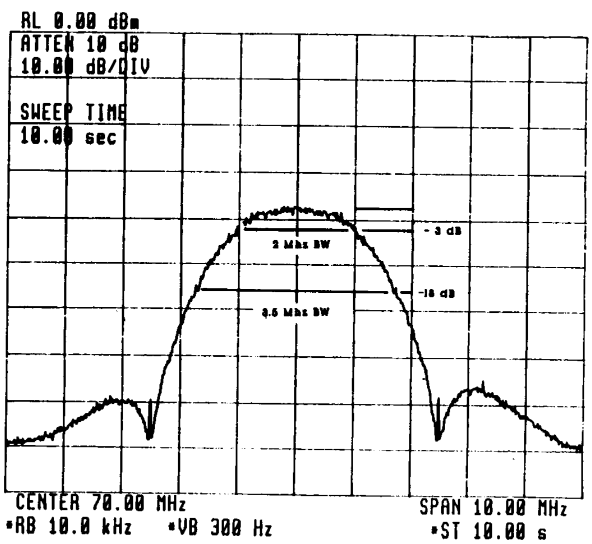

Figure 4. MITREX Modem Output Spectrum

Earth Stations

The earth station requirements to operate a time transfer link are quite modest.

The attached link budgets assume the use of 1.8 m K-band stations as a minimum size. This certainly is not the absolute minimum, but it does represent a useful compromise of physical size, link power requirements, and sidelobe performance. Therefore a station equipped with a solid state amplifier would 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 dBi, and θ 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 dBi 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 INTELNET service definition and tariffs. The occasional-use option would probably satisfy the requirements for periodic coordination links between various national standard labs.

Appendix 1.

INTELSAT Operations
Representatives

Canada	Mr. M. Stephens Teleglobe Canada 680 Sherbrooke St West Montreal, Quebec, H3A 2S4 CANADA Tel. 514-289-7584 Tlx. 9224 Ms. G. Pazos 514-289-7771
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Sweden	Barbro Svensson Televerket S-123 86 Farsta SWEDEN Tel. 8-713-1568 Tlx. 14970 GENTEL S
Switzerland	Mr. P. Breu General Directorate PTT Radio and Television Main Division Satellite Communications Branch Speichergasse 6 CH-3030 Berne, Switzerland Tel. 31-623756 Tlx. 911025 Mr. P. Chablais 31-622533

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Appendix 2.

Occasional-Use Frequencies

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