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| U.S. Radiocommunications Sector  Fact Sheet | |
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| |  | | --- | | **Document Title:** Working document towards a preliminary draft new Recommendation Itu-r m.[cnpc\_char\_5GHz] - **Characteristics and protection criteria of terrestrial and satellite unmanned aircraft system control and non-payload communications links operating in the aeronautical mobile (route) service and**  **aeronautical mobile satellite (R) service in the band 5 030-5 091 MHz** | | |
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| **Purpose/Objective:** The purpose of this contribution is to propose an update to the terrestrial and satellite characteristics based on a recent update to the RTCA MOPS DO-362A and EUROCAE MOPS ED-265 that standardize and define this CNPC Link. | |
| **Abstract:** This contribution contains characteristics and protection criteria for terrestrial and satellite based systems that can be used for remote control of unmanned aircraft. | |

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| **Radiocommunication Study Groups** |  |
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| Working document towards a preliminary draft new Recommendation Itu-r m.[cnpc\_char\_5GHz] | |
| **Characteristics and Protection Criteria of Terrestrial and Satellite Unmanned Aircraft System Control and Non-Payload Communications Links  operating in the aeronautical mobile (route) service and aeronautical  mobile satellite (R) Service in the band 5 030-5 091 MHz** | |

**Introduction**

At WRC-2012 it was agreed, under RR No. **5.443C**, that the frequency band 5 030-5 091 MHz could be used by the aeronautical mobile (R) service limited to internationally standardized aeronautical systems. Industry, international standards development organizations and ICAO have been working since then to develop the technology and standards necessary to use that allocation. Consequently, it is now possible to provide characteristics and protection criteria for such systems for use in any future sharing studies within ITU-R.

**Proposal**

The United States of America proposes to assist in answering the above need by providing characteristics for such Control and Non-Payload Communications (CNPC) links operating in the AM(R)S allocation under RR No. **5443C** and used in air-ground applications between Unmanned Aircraft (UA) and their Control Station (CS) where the Remote Pilot (RP) is located.

**Attachment**: 1

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ATTACHMENT

WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[CNPC\_CHAR\_5GHZ]

**Characteristics and Protection Criteria of Terrestrial and Satellite Unmanned Aircraft System Control and Non-Payload Communications Links**

**operating in the aeronautical mobile (route) service and aeronautical**

**mobile satellite (R) Service in the band 5 030-5 091 MHz**

**Scope**

This Recommendation specifies the characteristics of control and non-payload communications (CNPC) links, carrying command and control (C2) information, operating in the aeronautical mobile (route) service (AM(R)S) and aeronautical mobile satellite (route) service (AMS(R)S) in the frequency band 5 030-5 091 MHz in order to be used in analysing compatibility between unmanned aircraft systems (UAS) CNPC C2 Links operating in the AM(R)S, as well in the AMS(R)S and other services.

**Keywords**

Unmanned aircraft systems

**Abbreviations/Glossary**

AM(R)S: Aeronautical mobile (route) service

AMS(R)S: Aeronautical mobile-satellite (route) service

ARS: Airborne radio system

ATC: Air traffic control

BLoS: Beyond line of sight

C2: Command and control

CNPC: Control and non-payload communication

CRC: Cyclic redundancy check

CS: Control station

DVB-RCS: Digital video broadcasting - return channel via satellite

FDMA: Frequency division multiple access

GES: Ground earth station

GMSK: Gaussian minimum shift keying

GRS: Ground radio system

ICAO: International Civil Aviation Organization

LoS: Line of sight

MSL: Mean sea level

QPSK: Quadrature phase shift keying

RPA: Remotely piloted aircraft

RR: Radio regulation

S&A: Sense and avoid

SCPC: Single channel per carrier

TCC: Turbo code comparison

TDD: Time division duplex

UA: Unmanned aircraft

UACS: Unmanned aircraft control station

UAS: Unmanned aircraft system

**Related ITU Recommendations, Reports**

*Recommendations*

*Reports*

ITU-R [M.2205](https://www.itu.int/pub/R-REP-M.2205) Results of studies of the AM(R)S allocation in the band 960-1 164 MHz and of the AMS(R)S allocation in the band 5 030-5 091 MHz to support control and non-payload communications links for unmanned aircraft systems

ITU-R [M.2233](https://www.itu.int/pub/R-REP-M.2233) Examples of technical characteristics for unmanned aircraft control and non-payload communications links

ITU-R [M.2171](https://www.itu.int/pub/R-REP-M.2171) Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace

The ITU Radiocommunication Assembly,

*considering*

*a)* that …

*recognizing*

*a)* that the frequency band 5 030-5 091 MHz is allocated to both the aeronautical mobile (route) service (AM(R)S) and the aeronautical mobile-satellite (route) service (AMS(R)S) and are planned to be used for unmanned aircraft (UA) control and non-payload communication (CNPC) command and control (C2) Links to support the safe operation of UA;

*b)* that the frequency band 5 030-5 091 MHz is also allocated to the aeronautical radionavigation service;

c) that UAS CNPC Links support the safeguarding of human life and property therefore RR No. **4.10** applies;

*d)* that some internationally standardized microwave landing systems operate in this band in accordance with RR No. **5.444**,

*e)* that from Radio Regulations (RR) No. **5.444**, in the frequency band 5 030-5 091 MHz, the requirements of microwave landing system have priority over other uses of this frequency band;

*f)* that use of the frequency band 5 030-5 091 MHz by the AM(R)S and AMS(R)S is limited to internationally standardized aeronautical systems in accordance respectively with RR No. **5.443C** and RR No. **5.443D**.

*recommends*

**1** that the technical and operational characteristics of the UA CNPC Links for command and control (C2) operating in the AM(R)S and AMS(R)S described in the Annex should be considered representative of AM(R)S and AMS(R)S systems operating in the frequency band 5 030-5 091 MHz and should be used in studies of compatibility with systems operating under an allocation to another service.

**2** that an aggregate interference protection criterion I/N for terrestrial system UAS CNPC receiving stations of −6 dB should be used.

Annex

**1 Introduction and scope**

The characteristics and protection criteria of unmanned aircraft systems (UAS) CNPC C2 Links and their spectrum requirements must support the safe operation of unmanned aircraft (UA) in non-segregated airspace. There is a strong and growing demand for the use of UAS (also known as remotely piloted aircraft systems (RPAS) within the international civil aviation organization (ICAO)) in civil applications. These UA flights will share airspace with passenger carrying aircraft so their operation needs to be managed to safely allow the introduction of this new paradigm in aviation.

As these communications are critical for a safe management of the controlled airspaces, especially in terminal approach areas with high density of aircraft, future ICAO standards are obviously mandatory for these kinds of communications.

The CNPC C2 Link between the unmanned aircraft control station (UACS) and the UA support the following two ways of communication:

*– The forward link*:To send telecommands to the unmanned aircraft for flight and navigation equipment control.

*– The return link*: To send telemetry (e.g. flight status) from the UA to the UACS. It is anticipated that in some flight conditions or in specific airspaces it may be necessary to downlink video streams.

The potential types of C2 information exchanges carried over the CNPC C2 Link system are:

The UA control – To support the remote pilot's activity to fly the UA, status information from the aircraft back to the remote pilot is essential on a frequent basis relative to the dynamics of the UA.

The UA avionics – Avionics systems send information (e.g. flight guidance system, flight management system, ATC communication, detect and avoid, weather radar, status reporting system) over the CNPC C2 Link system from the UA to the UACS.

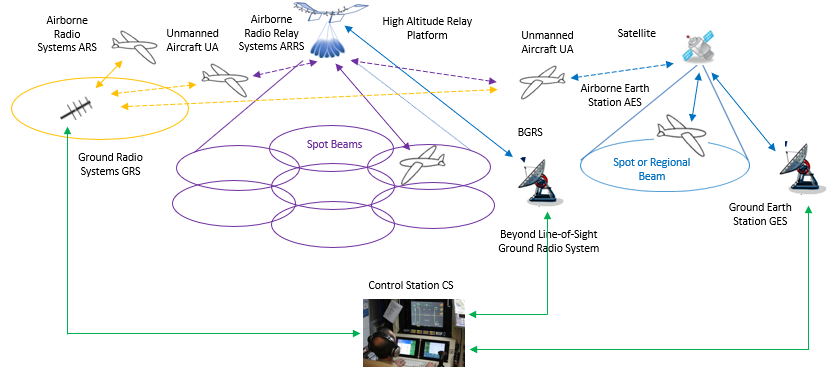
One aspect of the management of safe UAS operations is the management of the interference received by the receivers that link the UA and the UA CS. To enable this interference analysis to be undertaken the characteristics and protection criteria for these links operating in the AM(R)S and AMS(R)S allocations under RR Nos. **5.443C** and **5.443D** are proposed. This recommendation contains those characteristics and protection criteria based on systems which are currently under development and that will have to comply with the international standardization being developed by ICAO.

The CNPC C2 Link consists of a suite of air-to-ground links that can be used simultaneously or independently, as required, to provide operational coverage and performance. In total it consists of a terrestrial based component, a high altitude relay based component and a satellite based component.

The terrestrial component uses an airborne radio system (ARS) on the UA to communicate with a ground radio system (GRS) that connects to the UACS. The high altitude relay component uses a similar airborne radio system (ARS) on the UA to communicate to a beyond line of sight ground radio system (via the airborne radio relay system ARRS) that connects to the UACS. The satellite component uses an airborne earth station (AES) on the UA to communicate with a ground earth station (via the geostationary satellite) that connects to the UACS.

Figure 1

**Example command and non-payload communications link system components**



**2 Characteristics of command and non-payload communication links at 5 GHz**

**2.1 Unmanned aircraft, airborne radio relay and control station characteristics for terrestrial control and non-payload communication link**

TABLE 1

**Transmission and reception characteristics for the terrestrial control   
and non-payload communication link System 1**

| Terrestrial command and non-payload communication System 1 | | | |
| --- | --- | --- | --- |
|  | Units | UA ARS | GRS or ARRS |
| Frequency of operation | MHz | 5 030 to 5 091 | 5 030 to 5 091 |
| Duplexing |  | Time division duplex (TDD) | Time division duplex (TDD) |
| Transmit/receive duration | msec | 60 Receive + 2.5 guard time  65 Transmit + 2.5 guard time | 60 Transmit + 2.5 guard time  65 Receive + 2.5 guard time |
| Modulation |  | GMSK or QPSK | GMSK or QPSK |
| Modulation symbol rates | ksps | GMSK: TBD  including error  correction/detection, guard times and synchronization overhead | GSMK: TBD  including error correction/detection, guard times and synchronization overhead |
| Forward error correction |  | GMSK: Rate 5/8 Turbo Conv.  Code  QPSK: Rate 5/9 and Rate 1/3 TCC | GMSK: Rate 5/8 Turbo Conv. Code  QPSK: Rate 5/9 and Rate 1/3 TCC |
| Error detection |  | 32-bit CRC | 32-bit CRC |
| Baseband Input/Output Signal |  | User Data | User Data |
| User data block size transmitted per TDD frame | bits | GMSK: TBD  QPSK @ TBD  QSPK @ TBS | GMSK: TBD  QPSK @ TBD  QSPK @ TBD |
| User data rates | kbps | GMSK Tx: 7.04, 16.0, 25.6 and 34.56  GSMK Rx: 7.04, 16.0 and 25.6  QPSK Tx/Rx @ 20 ksps: 20.64 and 34.88;  Includes TDD duty cycle overhead | GMSK Rx: 7.04, 16.0, 25.6 and 34.56  GSMK Tx: 7.04, 16.0 and 25.6  QPSK Tx/Rx @ 20 ksps: 20.64 and 34.88;  Includes TDD duty cycle overhead |
| Occupied bandwidth, C | kHz | Variable per application with a maximum of 250 | Variable per application with a maximum of 250 |
| Antenna gain | dBi | 2 | 22.5 |
| Cable loss | dB | 2 | 1 |
| Antenna pattern |  | Constant azimuth  Constant elevation | Constant azimuth  Tailored in elevation  See Table 2 |
| Antenna polarization |  | Vertical with aircraft flying straight and level | Vertical |
| Maximum antenna height | m | 22 860 (MSL)  Typical 8 000 | 2 to 50  Typical 10 |
| Service range | km | 550  Typical 200 | 550  Typical 200 |
| Transmitter conducted power | dBm | 40 | 40 |
| Transmitter in band emission limits | dBc/kHz | −96 at 2 MHz offset  See Table 3 | −96 at 2 MHz offset  See Table 3 |
| Receiver noise figure | dB | 7 | 7 |
| Receiver sensitivity | dBm | GMSK: TBD  QPSK @ TBD  QSPK @ TBD | GMSK: TBD  QPSK @ TBD  QSPK @ TBD |
| Receiver in band rejection – except the operating channel | dB | One channel separation: 23  Two channel separation: 43  Three channel separation: 57  2 MHz or more separation: 63 | One channel separation: 23  Two channel separation: 43  Three channel separation: 57  2 MHz or more separation: 63 |
| Protection criteria (aggregate) I/N | dB | -6 | -6 |
|  | | | |



TABLE 2

**Control station elevation antenna pattern  
is constant in azimuth for System 1**

|  |  |
| --- | --- |
| System 1 | |
| Elevation degrees | Gain dBi |
| 0.5 | 21.5 |
| 1.5 | 22.0 |
| 2.5 | 22.5 |
| 3.5 | 22.0 |
| 7 | 19.5 |
| 11.5 | 16.5 |
| 16 | 14.0 |
| 32 | 9.0 |
| 64 | 4.0 |
| >75 | 3.0 |

*[Reply Antenna has a peak gain of 21.5dBi and a front-to-back ratio of 18.5dB so gain to back is 3dB]*



TABLE 3

**Transmitter out of channel emission limits in the 5030-5091MHz band for System 1**

|  |  |
| --- | --- |
| System 1 | |
| Offset from carrier frequency | dBc/kHz |
| Channel width ÷ 2 | −54 |
| 1.5 × channel width | −74 |
| 500 kHz | −90 |
| 2 000 kHz | −96 |

*[Reply see title change]*

TABLE 4

**Transmitter out of band emission limits**

|  |  |  |
| --- | --- | --- |
|  | Maximum command and non-payload communication link system power spectral density in the out of band domain | |
|  | AES | GES or ARRS |
| System 1 | *TBD* | *TBD* |

*[Editor’s note: It is envisioned that the proposed Recommendation will eventually include the out of band emission characteristics of AM(R)S transmissions into adjacent bands including those below 5 030 MHz that would be necessary for sharing studies to resolve the provisional nature of the ‑75 dBW/MHz protection value in RR No.* ***5.443C****.]*

TABLE 5

**Terrestrial System 1 Link Budget**

**TBD**

**2.2 Unmanned aircraft and control station characteristics for control and non-payload communication link via satellite**

**2.2.1 Control and non-payload communication via satellite system 1**

It is to be noted that:

– feeder links between the UACS and the satellite are assumed to be in the frequency band 5 030-5 091 MHz, but may also be accommodated in other frequency bands;

– a QPSK 1/2 digital video broadcasting - return channel via satellite (DVB-RCS) type waveform is considered;

– the availability (link availability from the ground earth station to the UA and from the UA to the ground earth station) considered in this example is 99.99%;

– the link budgets are performed for UA and UACS located in Western Europe, corresponding to the worst case in terms of sharing with microwave landing system (according to ICAO database used in Report ITU-R M.2205). On other areas more favourable from a sharing point of view, additional margin is available;

– the path loss includes the degradation due to atmospheric effects. The multipath and scintillation effects are included in the 3 dB link budget margin. Such a value is consistent with the margins needed for multipath and scintillation in the propagation channel of the 1.5/1.6 GHz aeronautical band;

– the link budget is carried out considering rain loss on the satellite – UA link, this representing the worst case compared to the UACS – Satellite link.

The feeder link is assumed to be in the frequency band 5 030-5 091 MHz, this case being the most restrictive one. A QPSK 1/2 DVB-RCS type waveform is considered. The availability (link availability from the ground earth station to the UA and from the UA to the ground earth station) that is considered is 99.99%.

TABLE 6

**Aeronautical mobile satellite (route) service return link budget for system 1**

| System |  |  | Repeater |  |
| --- | --- | --- | --- | --- |
| Availability (%) | 99.99% |  | Repeater gain (dB) | 110.5 |
| Satellite longitude (degrees) | –2.8 |  | Tx feeder loss (dB) | 1.0 |
| Conditions | Rain UL |  | Amplifier BO (OBO) (dB) | 3.5 |
| Modulation | QPSK 1/2 |  | Amplifier NPR (dB) | 17.0 |
| Useful bit rate per carrier (kbps) | 44.0 |  | *C*/*IM*0 degradation (dB/Hz) | 67.2 |
| Duplex ratio | 0.5 |  |  |  |
| Symbol rate per carrier (kbauds) | 103.5 |  | Satellite Tx antenna |  |
| Minimum bandwidth per carrier (kHz) | 139.8 |  | Tx antenna diameter (m) | 6.0 |
|  |  |  | Tx e.i.r.p. per carrier (dBW) | 14.1 |
| Aircraft Earth stations |  |  | Max Tx e.i.r.p. per carrier (dBW) | 17.1 |
| Frequency (MHz) | 5 000 |  | Downlink *C*/*I* inter-spots (dB) | 17.0 |
| Elevation (degrees) | 39.5 |  | Downlink *C*/*I*0 inter-spots (dB/Hz) | 67.2 |
| Carrier HPA power (W) | 20.0 |  |  |  |
| Antenna gain (dBi) | 3.0 |  | Downlink propagation |  |
| Tx loss (dB) | 2.0 |  | Total path loss (dB) | 198.0 |
| Power control uncertainty (dB) | 0.5 |  |  |  |
| Tx e.i.r.p. per carrier (dBW) | 13.5 |  | Ground Earth station |  |
|  |  |  | Downlink frequency (MHz) | 5 000 |
| Uplink propagation |  |  | Elevation (deg) | 39.5 |
| Total path loss (dB) | 198.5 |  | Antenna diameter (m) | 3.8 |
|  |  |  | *G*/*T* (dB/K) | 18.8 |
| Satellite Rx antenna |  |  | Downlink *C*/*N*0 (dB/Hz) | 63.5 |
| Rx antenna diameter (m) | 6.0 |  |  |  |
| Rx antenna gain (dBi) | 45.1 |  | Demodulation |  |
| Rx feeder loss (dB) | 0.5 |  | MLS degradation (dB) | 1.0 |
| Satellite *G*/*T* (dB/°K) | 18.7 |  | Total *C*/(*N*0+*IM*0+*I*0) (dB/Hz) | 57.0 |
| Uplink *C*/*N*0 (dB/Hz) | 62.4 |  | Total *C*/(*N*+*IM*+*I*) (dB) | 6.8 |
| Uplink *C*/*I*0 inter-spots (dB/Hz) | 67.2 |  | Required *C*/(*N*0+*IM*0+*I*0) (dB/Hz) | 54.0 |
| Uplink *C*/*I* inter-spots (dB) | 17.0 |  | Required *C*/(*N*+*IM*+*I*) (dB) | 3.8 |
|  |  |  | Margin (dB) | 3.0 |

TABLE 7

**Aeronautical mobile satellite (route) service forward link budget for system 1**

| **System** |  |  | **Repeater** |  |
| --- | --- | --- | --- | --- |
| Availability (%) | 99.99% |  | Repeater gain (dB) | 104.5 |
| Satellite longitude (degrees) | –2.8 |  | Tx feeder loss (dB) | 1.0 |
| Conditions | Rain DL |  | Amplifier BO (OBO) (dB) | 4.0 |
| Modulation | QPSK ½ |  | Amplifier NPR (dB) | 17.0 |
| Useful bit rate per carrier (kbps) | 7.0 |  | *C*/*IM*0 degradation (dB/Hz) | 59.2 |
| Duplex ratio | 0.5 |  |  |  |
| Symbol rate per carrier (kbauds) | 16.5 |  | **Satellite Tx antenna** |  |
| Minimum bandwidth per carrier (kHz) | 22.2 |  | Tx antenna diameter (m) | 6.0 |
|  |  |  | Tx e.i.r.p. per carrier (dBW) | 44.7 |
| **Ground Earth station** |  |  | Max Tx e.i.r.p. per carrier (dBW) | 47.7 |
| Frequency (MHz) | 5.000 |  | Downlink *C*/*I* inter-spots (dB) | 17.0 |
| Elevation (degrees) | 39.5 |  | Downlink *C*/*I*0 inter-spots (dB/Hz) | 59.2 |
| Number of carriers | 20 |  |  |  |
| HPA power (W) | 100.0 |  | **Downlink propagation** |  |
| Antenna diameter (m) | 3.8 |  | Total path loss (dB) | 198.5 |
| Antenna gain (dBi) | 44.1 |  |  |  |
| Tx loss (dB) | 1.0 |  | **Aircraft Earth station** |  |
| Power control uncertainty (dB) | 0.5 |  | Downlink frequency (MHz) | 5.000 |
| Tx e.i.r.p. per carrier (dBW) | 49.6 |  | Elevation (deg) | 39.5 |
|  |  |  | *G*/*T* (dB/K0 | –23.0 |
| **Uplink propagation** |  |  | Downlink *C*/*N*0 (dB/Hz) | 51.9 |
| Total path loss (dB) | 198.0 |  | Downlink *C*/*N* (dB) | 9.7 |
|  |  |  |  |  |
| **Satellite Rx antenna** |  |  | **Demodulation** |  |
| Rx antenna diameter (m) | 6.0 |  | MLS degradation (dB) | 1.0 |
| Rx antenna gain (dBi) | 45.1 |  | Total *C*/(*N*0+*IM*0+*I*0) (dB/Hz) | 49.0 |
| Rx feeder loss (dB) | 0.5 |  | Total *C*/(*N*+*IM*+*I*) (dB) | 6.8 |
| Satellite *G*/*T* (dB/K) | 18.7 |  | Required *C*/(*N*0+*IM*0+*I*0) (dB/Hz) | 46.0 |
| Uplink *C*/*N*0 (dB/Hz) | 98.9 |  | Required *C*/(*N*+*IM*+*I*) (dB) | 3.8 |
| Uplink *C*/*I*0 inter-spots (dB/Hz) | 59.2 |  | Margin (dB) | 3.0 |
| Uplink *C*/*I* inter-spots (dB) | 17.0 |  |  |  |

*[Editor’s note: The previous table was quoted from Report ITU-R M.2233 (Annex 3 § 6)]*

**2.2.2 Control and non-payload communication via satellite system 2**

It is to be noted that:

– The overall CNPC C2 link comprises the links between the remote pilot station / ground earth station (GES) and the satellite, as well as between the satellite and the remotely piloted aircraft (RPA).

– The feeder link i.e. the section of the CNPC C2 link from the satellite to the GES and from the GES to the satellite is assumed to provide equivalent or better performance than the section of the CNPC C2 link between the satellite and the RPA.

Table 8 and Table 9 provide the technical characteristics and link budgets for the portions of the forward and return link between the satellite and the RPA.

TABLE 8

**Satellite C band system link budget for system 2 (worst case)**

| Return link | |  | Forward link | |
| --- | --- | --- | --- | --- |
| System |  |  | System |  |
| Availability (%) | 99.99% (TBC) |  | Availability (%) | 99.99% (TBC) |
| Satellite longitude (degrees) | TBD |  | Satellite longitude (degrees) | TBD |
| Conditions | Clear Sky |  | Conditions | Clear Sky |
| Modulation | QPSK 1/3 |  | Modulation | QPSK 1/3 |
| Instantaneous Bearer Data Rate (kbps) | 83.3 |  | Instantaneous Bearer Data Rate (kbps) | 95.2 |
| Duplexing | Time Division Duplex (TDD) |  | Duplexing | Time Division Duplex (TDD) |
| Transmit/receive duration (msec) Up from Satellite Down from the UA | 25 Up plus 20 Guard,  85 Down plus 20 Guard |  | Transmit/receive duration (msec) Up from Satellite Down from the UA | 25 Up plus 20 Guard,  85 Down plus 20 Guard |
| Duplex ratio | 0.3 |  | Duplex ratio | 0.7 |
| Symbol rate per carrier (kbauds) | 278 |  | Symbol rate per carrier (kbauds) | 317 |
| Minimum bandwidth per carrier (kHz) | 347 |  | Minimum bandwidth per carrier (kHz) | 397 |
|  |  |  |  |  |
| Aircraft Earth stations |  |  | Satellite Tx antenna |  |
| Frequency (MHz) | 5 090 |  | Frequency (MHz) | 5 090 |
| Elevation (degrees) | 30 |  | Elevation (degrees) | 30 |
| Tx power (W) | 25.0 |  | Tx power per bearer (W) | 20.0 |
| Antenna gain (dBi) | 7.23 |  | Antenna gain (dBi) | 33.8 |
| Tx loss (dB) | 0.0 (TBC) |  | Tx loss (dB) | 1.0 |
| Tx e.i.r.p. per carrier (dBW) | 21.2 |  | Tx e.i.r.p. per bearer (dBW) | 45.8 |
|  |  |  |  |  |
|  |  |  |  |  |
| Uplink propagation |  |  | Downlink propagation |  |
| Total path loss (dB) | 198.4 |  | Total path loss (dB) | 198.4 |
|  |  |  |  |  |
| Satellite Rx antenna |  |  | Aircraft Earth station |  |
| Rx antenna diameter (m) | 1.64 |  | Downlink frequency (MHz) | 5090 |
| Rx antenna gain (dBi) | 33.8 |  | Elevation (deg) | 30 |
| Rx loss (dB) | 0.5 (TBC) |  | Rx antenna gain (dBi) | 7.23 |
| Satellite *G*/*T* (dB/°K) | 6.3 |  | *G*/*T* (dB/°K) | -17.5 |
| Uplink *C*/*N*0 (dB/Hz) | 54.7 |  | Downlink *C*/*N*0 (dB/Hz) | 55.5 |

TABLE 9

**Satellite C band system link budget for system 2 (best case)**

| Return link | |  | Forward link | |
| --- | --- | --- | --- | --- |
| System |  |  | System |  |
| Availability (%) | 99.99% TBD |  | Availability (%) | 99.99% TBD |
| Satellite longitude (degrees) | TBD |  | Satellite longitude (degrees) | TBD |
| Conditions | Clear Sky |  | Conditions | Clear Sky |
| Modulation | QPSK 1/3 |  | Modulation | QPSK 1/3 |
| Instantaneous Bearer Data Rate (kbps) | 83.3 |  | Instantaneous Bearer Data Rate (kbps) | 95.2 |
| Duplexing | Time Division Duplex (TDD) |  | Duplexing | Time Division Duplex (TDD) |
| Transmit/receive duration (msec) Up from Satellite Down from the UA | 25 Up plus 20 Guard, 85 Down plus 20 Guard |  | Transmit/receive duration (msec) Up from Satellite Down from the UA | 25 Up plus 20 Guard, 85 Down plus 20 Guard |
| Duplex ratio | 0.3 |  | Duplex ratio | 0.7 |
| Symbol rate per carrier (kbauds) | 278 |  | Symbol rate per carrier (kbauds) | 317 |
| Minimum bandwidth per carrier (kHz) | 347 |  | Minimum bandwidth per carrier (kHz) | 397 |
|  |  |  |  |  |
| Aircraft Earth stations |  |  | Satellite Tx antenna |  |
| Frequency (MHz) | 5 090 |  | Frequency (MHz) | 5 090 |
| Elevation (degrees) | 90 |  | Elevation (degrees) | 90 |
| Tx power (W) | 25.0 |  | Tx power per bearer (W) | 20.0 |
| Antenna gain (dBi) | 11.1 |  | Antenna gain (dBi) | 37.8 |
| Tx loss (dB) | 0.0 (TBC) |  | Tx loss (dB) | 1.0 |
| Tx e.i.r.p. per carrier (dBW) | 25.1 |  | Tx e.i.r.p. per bearer (dBW) | 49.8 |
|  |  |  |  |  |
|  |  |  |  |  |
| Uplink propagation |  |  | Downlink propagation |  |
| Total path loss (dB) | 197.7 |  | Total path loss (dB) | 197.7 |
|  |  |  |  |  |
| Satellite Rx antenna |  |  | Aircraft Earth station |  |
| Rx antenna diameter (m) | 1.64 |  | Downlink frequency (MHz) | 5090 |
| Rx antenna gain (dBi) | 37.8 |  | Elevation (deg) | 90 |
| Rx loss (dB) | 0.5 (TBC) |  | Rx antenna gain (dBi) | 11.1 |
| Satellite *G*/*T* (dB/°K) | 10.3 |  | *G*/*T* (dB/°K) | -13.6 |
| Uplink *C*/*N*0 (dB/Hz) | 63.3 |  | Downlink *C*/*N*0 (dB/Hz) | 64.1 |

TABLE 10

**Satellite & aircraft transmit mask for system 2, with transmit bandwidth BTx=400 kHz**

|  | **Rejection** | **Bandwith** |
| --- | --- | --- |
| 0 | 0 dBc | < BTx |
| 1 | −50 dBc | 3. BTx |
| 2 | −72 dBc | 1.0 MHz |

TABLE 11

**Satellite & aircraft receive mask for system 2, with receive bandwidth BRx=400 kHz**

|  | **Rejection** | **Bandwith** |
| --- | --- | --- |
| 1 | 0 dBc | < BRx |
| 2 | −50 dBc | 3. BRx |
| 3 | −74 dBc | 4.0 MHz |