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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 |

(202X)

**Scope**

This Recommendation specifies the characteristics of CNPC C2 Links 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) control and non-payload communication (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 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) 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 and used by the globally standardized microwave landing system,

[Chairman’s note: these seem more like recognizing’s than considering’s, and I don’t believe they are allocated for specific purposes]

recognizing

*a)* 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;

*b)* 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,

recommends

that the technical and operational characteristics of the UA CNPC C2 Links 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 used in studies of compatibility with systems operating under an allocation to another service.

Annex

# 1 Introduction and scope

The Characteristics of Unmanned Aircraft Systems (UAS) control link s(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 Command and Control (C2) Link between the UACS and the UA support the following two ways of communication:

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

*– The downlink*: 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 could be necessary to downlink video streams.

In areas under the responsibility of the aeronautical authorities, the C2 communications will have to be compliant with ICAO standards. Nevertheless, in the periods where the UA will follow a full autonomous flight, the up and down links could have very low data rates.

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

The UA control – To support the remote pilot's activity to fly the UA, power plant 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 C2 link system from the UA to the Control Station (UA CS).

In non-segregated airspace a link between air traffic control (ATC) and the UA Control Station (UA CS) via the UA, called ATC relay, will be required to relay ATC and air-to-air communications received and transmitted by the UA.

For communicating with ATC, the UA uses the same equipment as a manned aircraft. This recommendation only considers the downlink bringing the ATC information from the UA to the UACS and the uplink from the UACS to the UA allowing the UA CS to communicate with ATC.

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. Additionally, since the frequency band covered in this recommendation is shared with other aeronautical systems (like microwave landing system under RR No. **5.444**), the interference caused by the UAS must also be managed to ensure that the levels of airspace safety are appropriately maintained.

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, which will eventually be included within Annex 10, Volume VI, of their Standards and Recommended Practices.

The Control and Non-Payload Communications system (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 Geostationary Satellite Orbit (GSO) 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 UA CS. 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 UA CS. The GSO 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 UA CS.



Figure 1

Command and Non-Payload Communications Link System Components

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

[Editor’s note: The number of terrestrial systems described in this section is to be lowered. The aim is to have fewer systems, compatible with satellite systems presented after, in accordance with technical characteristics provided by ICAO]

## 2.1 Unmanned aircraft 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 CNPC System 1 |
| --- |
|  | Units | Airborne | Ground |
| 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 Up from control station Down from the UA | msec | TBD | TBD |
| Modulation |  | GMSK or QPSK | GMSK or QPSK |
| Modulation symbol rates | ksps | GMSK: TBD including error correction/detection, guard times and synchronization overhead | GSMK: TBDincluding error correction/detection, guard times and synchronization overhead |
| Forward error correction |  | GMSK: Rate 5/8 Turbo Conv.CodeQPSK: Rate 5/9 and Rate 1/3 TCC | GMSK: Rate 5/8 Turbo Conv. CodeQPSK: 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: TBDQPSK @ TBDQSPK @ TBS | GMSK: TBDQPSK @ TBDQSPK @ TBD |
| User data rates | kbps | GMSK Tx: 7.04, 16.0, 25.6 and 34.56GSMK Rx: 7.04, 16.0 and 25.6QPSK Tx/Rx @ 20 ksps: 20.64 and 34.88;Includes TDD duty cycle overhead | GMSK Rx: 7.04, 16.0, 25.6 and 34.56GSMK Tx: 7.04, 16.0 and 25.6QPSK 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 azimuthConstant elevation | Constant azimuthTailored in elevationSee Table 2 |
| Antenna polarization |  | Vertical with aircraft flying straight and level | Vertical |
| Maximum antenna height | m | 22 860 (MSL)Typical 8 000 | 2 to 50Typical 10 |
| Service range | km | 550Typical 200 | 550Typical 200 |
| Transmitter conducted power | dBm | 40 | 40 |
| Transmitter in band emission limits | dBc/kHz | −96 at 2 MHz offsetSee Table 3 | −96 at 2 MHz offsetSee Table 3 |
| Receiver noise figure | dB | 7 | 7 |
| Receiver sensitivity | dBm | GMSK: TBDQPSK @ TBDQSPK @ TBD | GMSK: TBDQPSK @ TBDQSPK @ TBD |
| Receiver in band rejection – except the operating channel | dB | One channel separation: 23Two channel separation: 43Three channel separation: 572 MHz or more separation: 63 | One channel separation: 23Two channel separation: 43Three channel separation: 572 MHz or more separation: 63 |
| Protection criteria \* |  | [TBD (see *editor’s note*)] | [TBD (see *editor’s note*)] |
| \**[Editor’s note: ICAO is invited to provide the technical performance criteria contained in its official documentation on this topic.]* |

TABLE 2

Transmission and reception characteristics for the terrestrial control
and non-payload communication link system 2

| Terrestrial CNPC System 2 |
| --- |
|  | Units | Airborne | Ground |
| Frequency of operation | MHz | 5 030 to 5 091 | 5 030 to 5 091 |
| User data rates | kbps | 7.04 to 34.8 | 7.04 to 34.8 |
| Duplexing |  | TDD | TDD |
| Transmit/receive duration up from control station down from the UA | msec | 25 Up plus 20 Guard85 Down plus 20 Guard | 25 Up plus 20 Guard85 Down plus 20 Guard |
| Modulation |  | TBD | TBD |
| Modulation symbol rates | ksps | TBD | TBD |
| Forward error correction |  | TBD | TBD |
| Error detection |  | 32-bit CRC | 32-bit CRC |
| User data block size transmitted per TDD frame | bits | TBD | TBD |
| User data rates | kbps | TBD | TBD |
| Occupied bandwidth, C | kHz | Variable per application with a maximum of 397 (TBC) | Variable per application with a maximum of 397 (TBC) |
| Antenna gain | dBi | 3 | 22.5 |
| Cable loss | dB | 2 | 3 |
| Antenna pattern  |  | Omni | 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 50Typical 10 |
| Service range | km | 50 (TBC) | 50 (TBC) |
| Transmitter conducted power | dBm | 30 (TBC) | 30 (TBC) |
| Transmitter out-of-band emission limits |  | See. Table XX (Table 4 at this stage) | See. Table XX (Table 4 at this stage) |
| Receiver noise figure | dB | 7 (TBC) | 7 (TBC) |
| Receiver sensibility | dBm | TBD | TBD |
| Receiver selectivity/blocking |  | See. Table XX (Table 5 at this stage) | See. Table XX (Table 5 at this stage) |
| Protection criteria \* |  | [TBD (see *editor’s note*)] | [TBD (see *editor’s note*)] |
| *\* [Editor’s note: ICAO is invited to provide the technical performance criteria contained in its official documentation on this topic.]* |

TABLE 2.1

Control station elevation antenna pattern
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 |

[Editor’s note: All the gains indicated for the antenna pattern in Table 2.1 are positive, which is questionable]

TABLE 2.2

Control station antenna pattern
Pattern for system 2

|  |
| --- |
| Antenna Pattern for System 2 |
| (*TBD*) |

TABLE 3

**Transmitter in band emission limits 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 |

[Editor’s note: It needs to be clarified how Table 3 is addressing out of channel emissions]

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 |
|  | Airborne  | Ground  |
| System 1 | *TBD* | *TBD* |
| System 2 | *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

Command and non-payload communication link system receiver selectivity/blocking limits

|  |  |  |
| --- | --- | --- |
|  | **Airborne** | **Ground** |
| System 1 | *TBD* | *TBD* |
| System 2 | *TBD* | *TBD* |

[Editor's note: Based on the limited information provide for terrestrial system 2 and due to the different TDD timing used by terrestrial system 1 and system 2 it appears that terrestrial system 1 and terrestrial system 2 may cause each other interference if the systems are located less than a TBD distance from each other.]

[Editor's note: Information on terrestrial system 2 has not been presented to ICAO.]

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

[Editor’s note: The number of satellite systems described in this section is to be lowered. The aim is to have fewer systems, compatible with terrestrial systems presented before, in accordance with technical characteristics provided by ICAO]

### 2.2.1 Satellite control and non-payload communication 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) Comparison should be made with other reports dealing with the same topic, in order to identify and complete missing parameters. Satellite antenna diameters should be checked as well for consistency.]

### 2.2.2 Satellite control and non-payload communication system 2

It is to be noted that:

– The overall CNPC 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 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 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 SatelliteDown from the UA | 25 Up plus 20 Guard,85 Down plus 20 Guard |  | Transmit/receive duration (msec)Up from SatelliteDown 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 SatelliteDown from the UA | 25 Up plus 20 Guard,85 Down plus 20 Guard |  | Transmit/receive duration (msec)Up from SatelliteDown 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 | $\geq $ 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 | $\geq $ 4.0 MHz |

[Editor's note: Based on the limited information provide for satellite system 2 and due to the different TDD timing used by satellite system 1 and system 2 it appears that satellite system 1 and satellite system 2 may cause each other interference if the systems are located less than a TBD distance from each other]

### 2.2.3 Satellite control and non-payload communication system 3

It is to be noted that:

– Satellite CNPC System 3 has been designed with a 50 msec TDD frame structure so that it is compatible with the terrestrial system 1, described in Section 2.1.

– The Downlink from the satellite to the UA uses a four colour reuse pattern splitting the 5 030-5 091 MHz allocation into four 15.25 MHz segments each supporting multiple UA with a 1msec TDMA timeslot.

– The Uplink from the UA to the satellite uses a variable bandwidth frequency division multiple access (FDMA)/ single channel per carrier (SCPC) technique to allow compatibility with the terrestrial system 1.

– Satellite feeder links between the UACS and the satellite are assumed to be in other frequency bands and are anticipated to have significantly higher performance than the satellite to UA links whose characteristics and protection criteria are described in Table 12.

TABLE 12

Transmission and reception characteristics for the satellite control and non-payload
communication link system 3

| Satellite CNPC System 3 |
| --- |
|  | **Units** | Airborne | Satellite |
| 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 Up from UA Down from the Satellite | msec | 22 Up plus 1.5 Guard17 Down plus 9.5 Guard | 22 Up plus 1.5 Guard17 Down plus 9.5 Guard |
| Modulation |  | DVB-S2 QPSK 3/4 | DVB-S2 QPSK 3/4 |
| Multiple Access Up from UA Down from the Satellite |  | FDMA/SCPC UpTDMA Down | FDMA/SCPC UpTDMA Down |
| TDMA Burst Length | msec | 1.0 | 1.0 |
| Modulation symbol ratesUp from UA Down from the Satellite | ksps | FDMA 20.1, 43.5, 92.0 UpTDMA 384 and 832 Downincluding error correction/detection, guard times and synchronization overhead | FDMA 20.1, 43.5, 92.0 UpTDMA 384 and 832 Downincluding error correction/detection, guard times and synchronization overhead |
| Forward error correction |  | DVB-S2 QPSK 3/4 | DVB-S2 QPSK 3/4 |
| Baseband Input/Output Signal |  | User Data | User Data |
| User data rates | kbps | 7.04, 16.0, 25.6 and 34.56Includes TDD duty cycle overhead | 7.04, 16.0, 25.6 and 34.56Includes TDD duty cycle overhead |
| Occupied bandwidth, CUp from UA Down from the Satellite | kHz | FDMA 17, 37, 77.3 UpTDMA 371, 804 Down | FDMA 17, 37, 77.3 UpTDMA 371, 804 Down |
| Antenna gain | dBic | 17 | 34 EOC |
| Cable loss | dB | 2 | 1 |
| Antenna pattern  | degree | 20Steerable in Elevation and Azimuth | 2 - spot beamwidth EOC |
| Antenna polarization |  | Circular | Circular |
| Maximum antenna height | m | 22 860 (MSL)Typical 8 000 | GSO orbit |
| Service range | km | 550Typical 200 | 37,620 +/- 1,1407.5 msec delay spread |
| Transmitter conducted power | dBm | 37 | 51 EOC |
| Transmitter in band emission limits | dBc/kHz | −96 at 2 MHz offsetSee Table 3 | −96 at 2 MHz offsetSee Table 3 |
| Receiver G/T | dB | -6.3 | 7 |
| Receiver in band rejection – except the operating channel | dB | One channel separation: 23Two channel separation: 43Three channel separation: 572 MHz or more separation: 63 | One channel separation: 23Two channel separation: 43Three channel separation: 572 MHz or more separation: 63 |
| Protection criteria |  | [TBD] | [TBD] |

## 2.3 Unmanned aircraft, satellite and ground control station characteristics for systems using simultaneously terrestrial and satellite control and non-payload communication link

[Editor’s note: this section is providing preliminary characteristics of solution providing simultaneous terrestrial and satellite link subject to revision after further development]

### 2.3.1 Terrestrial and satellite architecture

Characteristics of Table 12 have been chosen to provide an example to ensure reliability of simultaneous transmissions between terrestrial and satellite control and non-payload communication links. It is based on similar principle as the one retains for automatic dependent surveillance-broadcast at 1 090 MHz using same equipment for LoS and BLoS by broadcasting same transmissions from aircraft. However, it has however that the CNPC link has to deal with both directions.

Short duration emissions presented in Table 13 allow low probabilities of collision between aircraft transmissions. Downlink durations emissions are supposed to be longer in order to comply with values of higher downlink’s data rates described in detail in Report ITU-R M.2171.

Typical data rates considered here are 10 kbits/s for uplink and 15 kbits for downlink (without non-payload video/weather radar).

TABLE 12

Frequency plan

| Type of link | Frequency band (MHz)  | Bandwidth (MHz) |
| --- | --- | --- |
| Ground Station - Unmanned aircraft link | 5 030-5 060 | 30 |
| Guard Band  | 5 060-5 061 | 1 |
| Unmanned aircraft - Satellite link | 5 061-5 091 | 30 |

TABLE 13

Modulation characteristics

| Characteristics | Units | Values |
| --- | --- | --- |
| Central frequency of pulses  | MHz | 5 045 and 5 075 |
| Modulation  | - | QPSK |
| Forward error correction | - | FEC 1/2 |
| Duplexing (TDD) | ms | 0.2 (Uplink) and 4 (Downlink) |
| Message Period | ms | 50 |
| Transmission rate | Hz | 20 |
| Spectral occupation | MHz | 30 |

### 2.3.2 Unmanned aircraft system - satellite budget link

Table 14 provides an example of the worst-case budget link between an unmanned aircraft and a satellite.

TABLE 14

Worst case budget link between unmanned aircraft and satellite

| Return Link | Forward Link |
| --- | --- |

|  |  |  |  |
| --- | --- | --- | --- |
| Characteristics | Values | Characteristics | Values |
| Modulation | QPSK ½ | Modulation | QPSK ½ |
| Symbol rate (Mbauds) | 10 | Symbol rate (Mbauds) | 10 |
| TDD (ms) | 0.2 Up plus,4 Down plus 45.8 Guard | TDD (ms) | 0.2 Up plus,4 Down plus 45.8 Guard |
| Message Period | 50 | Message Period | 50 |
| Transmission rate | 20 | Transmission rate | 20 |
| Useful bit rate (kbps) | 80 | Useful bit rate (kbps) | 80 |

|  |  |  |  |
| --- | --- | --- | --- |
| Bandwidth (MHz) | 30 | Bandwidth (MHz) | 30 |
|  |  |  |  |
| **Aircraft Earth stations** |  | **Satellite Tx antenna** |  |
| Frequency (MHz) | 5 090 | Altitude(km) | 800 |
| Elevation (degrees) | 90 | Elevation (degrees) | 90 |
| Tx power (W) | 25.0 | Tx power (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 (dBW) | 49.8 |
| **Downlink propagation** |  |  |  |
| Total path loss (dB) | 165 | **Downlink propagation** |  |
|  |  | Total path loss (dB) | 165 |
| **Satellite Rx antenna** |  |  |  |
| Altitude(km) | 800 | **Aircraft Earth station** |  |
| Rx antenna diameter (m) | 1.64 |  |  |
| 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 |
| *C*/*N*0 (dB/Hz) | TBD | *C*/*N*0 (dB/Hz) | TBD |