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Fixed Satellite Service allocations for RPAS C2 Links

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Preparatory Workshop for World Radiocommunication Conference for 2023 (WRC-23)

Cairo, Egypt, 28-29 August 2023

ITU-R Resolution 155 Status Update

- **Background**
 - Brief history
 - Identified frequency allocations
 - ICAO responsibilities
- **Regulatory considerations**
 - Principals e.g., operate as a typical FSS Earth station
 - Notification and coordination
 - Identifying responsibilities
- **Technical considerations**
 - RPA/UA Earth station characteristics
 - Protecting incumbent services – pfd mask
 - Link Budgets
- **Resolution 155 WRC-19 overview**
- **Anticipated changes to Resolution 155 for WRC-23**
- **ICAO Position and WRC-23 desired outcome**



Brief History

- **Report ITU-R M.2171, 12/2009 = Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non segregated airspace**
 - Identified the need for at least 56MHz (and possibly 198MHz) of spectrum for the projected number of UAS/RPAS anticipated to be operating in the 2030 timeframe
 - In 2009 only L Band AMS(R)S systems existed but with an inadequate spectrum capacity
 - A coprimary AM(R)S and AMS(R)S allocation exists at 5030-5091MHz but to date no satellite systems are operating and some of the band would need to be set aside for AM(R)S
 - Already operating Ku and Ka Band FSS systems were identified as a potential solution, but they are not AMS(R)S
- **Resolution 155, WRC-2015**
 - Regulatory provisions related to earth stations on board unmanned aircraft which operate with geostationary-satellite networks in the fixed-satellite service in certain frequency bands not subject to a Plan of Appendices 30, 30A and 30B for the control and non-payload communications of unmanned aircraft systems in non-segregated airspaces
- **Resolution 155, WRC-2019**
 - Minor update to recognize a second pfd mask to protect terrestrial services based on work carried out during the 2015-2019 study cycle



Identified Frequency Allocations

resolves

1 that assignments to stations of geostationary FSS satellite networks operating in the frequency bands 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) in Region 2, 12.2-12.5 GHz (space-to-Earth) in Region 3, 12.5-12.75 GHz (space-to-Earth) in Regions 1 and 3 and 19.7-20.2 GHz (space-to-Earth), and in the frequency bands 14-14.47 GHz (Earth-to-space) and 29.5-30.0 GHz (Earth-to-space), may be used for UAS CNPC links in non-segregated airspace⁸, provided that the conditions specified in *resolves* below are met;

- **Ku space-to-Earth = 10.95-12.75GHz (region dependent)**
- **Ku Earth-to-space = 14-14.47GHz**

- **Ka space-to-Earth = 19.7-20.2GHz**
- **Ka Earth-to-space = 29.5-30GHz**

- **FSS C Band (3-4GHz/5-6GHz) not considered because of the limited antenna size on the RPA/UA not providing sufficient link margin**



ICAO Responsibilities

instructs the Director of the Radiocommunication Bureau

5 to report to subsequent WRCs on the progress made by ICAO on the development of SARPs for UAS CNPC links,

invites the International Civil Aviation Organization

to provide to the Director of the Radiocommunication Bureau, in time for WRC-19 and WRC-23, information on ICAO efforts regarding implementation of UAS CNPC links, including the information related to the development of SARPs for UAS CNPC links.

- **ICAO SARPs, covering all C2 Link technologies, are being developed within the RPAS Panel**
 - New Volume VI, in Annex 10, for C2 Link SARPs
 - Part I (Procedures) adopted in February 2021 and are now effective
 - Part II (Systems) endorsed by RPAS Panel and are anticipated to be adopted in Q1 2025
 - Will be in State Letter review by WRC-2023
- **A companion “Manual on C2 Links for RPAS” is also being developed**
 - First release to coincide with Part II (Systems) State Letter review in 2023
 - Covers key concepts such as C2 Service Providers and Required Link Performance (RLP) and will be regularly updated as new C2 Link technologies are approved



Regulatory Considerations - Principals

- **Principals**

- Only communicate with GSO FSS Satellites in particular Ku and Ka frequency bands
- Do not cause more interference nor claim more protection than any Typical FSS Earth station in that network
- Do not constrain other FSS satellite networks beyond that of Typical FSS Earth stations associated with the network
- Accept the interference from and not cause harmful interference to stations of terrestrial services
- Maintain antenna pointing accuracy without inadvertently tracking adjacent GSO satellites
- Use a network control and monitoring center or similar facility to monitor regulatory compliance
- Ensure that ICAO SARPs consistent with Article 37 of the Convention on International Civil Aviation are satisfied
- Ensure freedom from harmful interference and act immediately to address such cases
- Take practical measures to protect Radio Astronomy sites when using the 14-14.7 GHz band
- Only allow operations within national territories, waters, and airspaces, when authorized by the administration of that territory



Regulatory Considerations - Notification and Coordination

- **Notification and coordination**

- Use Typical FSS Earth Station assignments already included in the notification or modified characteristics that do not change interference envelope
- Use only assignments successfully coordinated under Article 9 with a favorable finding under Article 11
- Do not use assignments for which the notifying administration accepts the interference as a basis for recording under No. 11.32 (See procedure of Appendix 5 § 6.d.i)



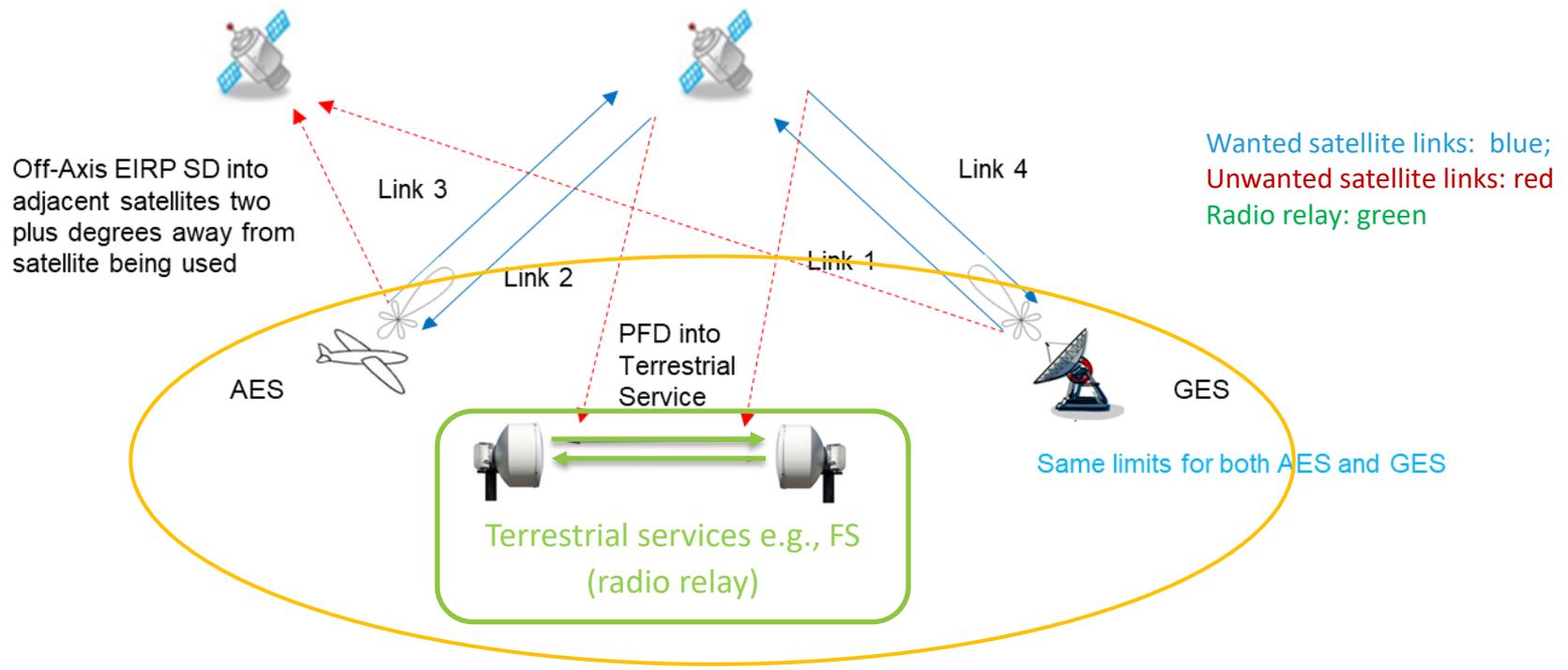
Regulatory Considerations - Responsibilities

- **Identifying responsibilities**
 - **Notifying Administration of the Satellite Network used by the RPA**
 - Coordinates and notifies network
 - Manages interference from their space station(s)
 - Prevents interference from the RPA Earth station by ensuring it meets coordination limits
 - Secures agreement from Administration of the territory where RPA operates
 - **Notifying Administration of other Satellite Networks**
 - Coordinates with notifying administration
 - Reports interference to their network(s) to Notifying Administration of the Satellite Network used by the RPA
 - **Flag Nation of the RPAS**
 - Ensures SARPs are met by RPAS
 - **Administration of the territory where RPA operations are conducted**
 - Provides agreement to operate over their territory
 - Reports interference received by their terrestrial services to Notifying Administration of the Satellite Network used by the RPA
 - **Administration of adjacent/nearby territories to where RPAS operations conducted**
 - Reports interference received to Administration of the territory where RPA operates
 - **Administration of the ground feeder link earth station is located**
 - Secures GES operating authority
 - Notifies ITU-R of their Specific Earth station

Technical Considerations

- Key system elements and influencing parameters

- Satellite with (edge of) coverage (orange): G_{max} (satellite) – x dB (typically -3dB to -5dB)
- Ground Earth Station (GES): Fixed station with large antenna gain/narrow pattern
- Remotely piloted aircraft (RPA), Airborne Earth Station (AES): small, fully steerable antenna with small antenna gain/wide pattern





Technical Considerations

- **Satellite Characteristics**

- Existing FSS satellites

- Classical wide beam satellites (low satellite gain): Peak antenna gains in the order of magnitude of 35 dBi (Ku band) and 43 dBi (Ka band), respectively
- High throughput satellites (HPS) with multi-spot beam architecture and high beam gains: Peak antenna gains in the order of magnitude of 40 dBi (Ku band) and 50 dBi (Ka band), respectively

- Typically, transparent satellite payloads without signal processing:

- Only downlink routing of uplink signals
- Transponder settings (e.g., saturated flux density = SFD) according to typical FSS operation
- C2 Links use shared transponder capacity or exclusive transponders (then adapted settings possible)

- Coverage

- full visibility area of the satellite (global beam, multi spot beam subsystem) or
- smaller parts of the visibility in case of regional / spot beams
- Minimum elevation of 15 degrees are recommended with consequent maximum latitudes: $\approx 67^{\circ}\text{S}$ to 67°N

- Link 1 and Link 4 as classical FSS links (from and to fixed large Earth stations)

- Link 2 and 3 are (possibly adapted) links (to and from the RPA), defining the end-to-end link performance limited by:

- RPA receive G/T (Link 2) limited by antenna size together with the (permissible) satellite EIRP
- RPA uplink EIRP (limited by off axis emission levels from small antenna) together with the satellite G/T (Link 3)



Technical Considerations

- **GES and AES Characteristics**

- **GES:**

- Hub or gateway stations with large antenna diameters and link management functions incl. uplink power control;
- Antenna sizes 4 m up to 15 m: Gains $\gg 50$ dBi;
- Fully compliant to FSS characteristics based on the ITU-R MIFR (upper half of the performance range) and FSS system implementations;
- Antenna gain pattern according to (mostly better than) Appendix 7 of ITU RR

- **AES:**

- Fully steerable antennas (reflector based or direct radiating phased array) with pointing performance throughout the full azimuth and elevation range;
- Antenna sizes 40 cm up to 1.3 m: Gains 35 ... 48 dBi;
- G/T and EIRP values like VSAT (very small aperture terminals): 13 ... 20 dB/K and 55 ... 68 dBW, respectively;
- To be compliant with FSS characteristics according to ITU-R MIFR (lowest 30% of the performance range);
- Antenna gain pattern according to Appendix 7 / 8 of ITU-R RR or to an envelope better adapted to the RPA operational case (Bessel function based);
- Performance improvement functions like Uplink Power Control and Adaptive Coding and Modulations necessary;



Technical Considerations

• Regulatory Limitations

– General ITU-R limits according to ITU-R RR:

- Satellite downlink: PFD limits (see Article 21) in Ku band
- Further limitations according to Article 21 and 22 ITU RR, like off-axis EIRP limits (Article 22.26, 22.32)
- Antenna gain envelopes according to ITU RR Appendix 7, 8

– Specific limits according to Resolution 155 (Rev. WRC-19) for Ku band uplinks

- Limitation of the off-axis EIRP from RPA / UA for protecting terrestrial services (mainly FS)

Res. 155, Annex 2, Example b:

An earth station on board UA in the frequency band 14.0-14.3 GHz shall comply with the pfd limits described below, on the territory of countries listed in No. 5.505:

$$15 \log (\vartheta + 0.9) - 124 \text{ dB(W/m}^2\text{/MHz) for } 0^\circ \leq \vartheta \leq 90^\circ$$

where ϑ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

An earth station on board UA:

- in the frequency band 14.25-14.3 GHz on the territory of countries listed in No. 5.508;
- in the frequency band 14.3-14.4 GHz in Regions 1 and 3;
- in the frequency band 14.4-14.47 GHz worldwide,

shall comply with the pfd limits described below:

$$15 \log (\vartheta + 0.9) - 133.5 \text{ dB(W/m}^2\text{/MHz) for } 0^\circ \leq \vartheta \leq 90^\circ$$

where ϑ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

NOTE – The aforementioned limits relate to the pfd and angles of arrival that would be obtained under free space propagation conditions.

– ITU-R Recommendations:

- Off-axis antenna gain envelopes according to Recommendation ITU-R S.524 (Ku and Ka band), S.728 (Ku band)



Technical Considerations - Link Budgets 1

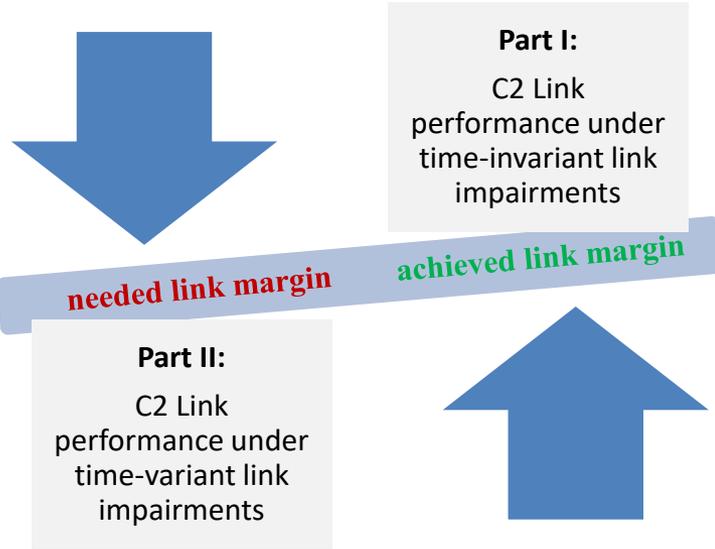
Part 1: Clear sky FSS link budgets, asymmetric design (in favor to link 1, 4 compared to link 2, 3)
Results: **Achieved** end-to-end link margins, separated for the links

Part 2: Link availability / continuity analyses against variable link impairments **based on the achieved link margin**
→ Results: Signal degradation times / probabilities;
Achieved versus required link performance

Achieved FSS satellite link performance fulfills the requirements

Achieved FSS satellite link performance not fulfilling the requirements

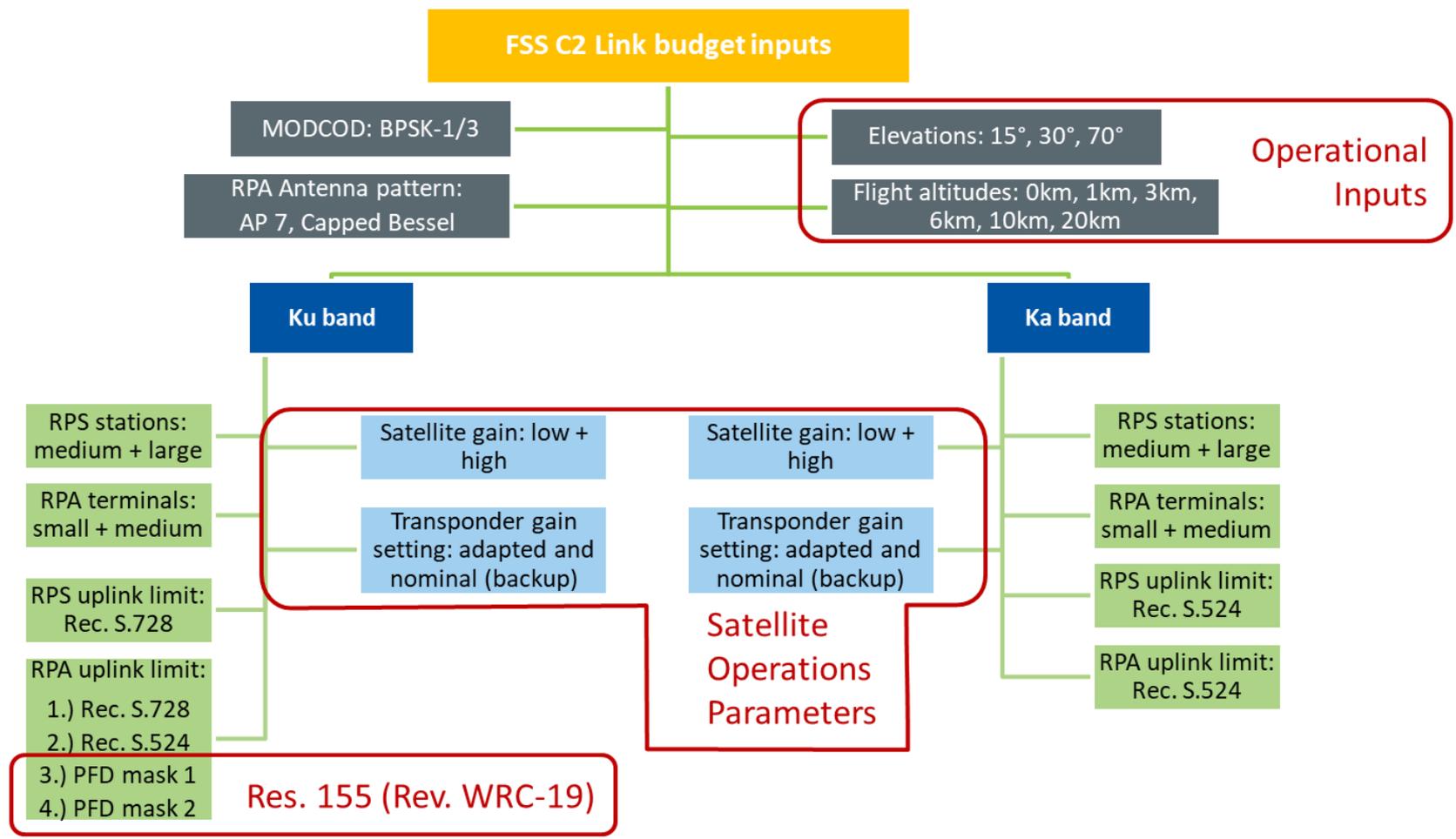
Including fixed interference influences (system internal and external) as well as time-variant interference influence towards Ku band RPAs (Link 2) caused by FS stations





Technical Considerations - Link Budgets 2

- Parameter variations (2880 individual link budgets)





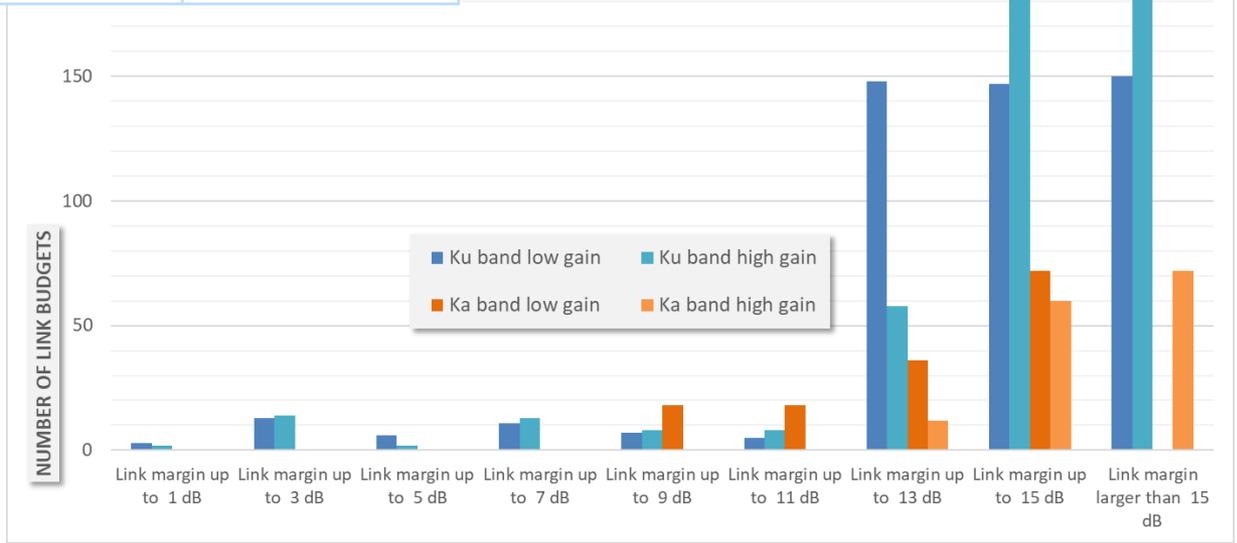
Technical Considerations - Link Budgets 3

FSS based C2 Link budgets with link margins > 0 dB

Fulfillment rates for	RPA antenna pattern per AP7	RPA antenna pattern per Capped Bessel
Ku band low gain satellite	67% - 69.1%	72.9% - 73.6%
Ku band high gain satellite	73.6% - 75.3%	79.9% - 80.2%
Ka band low gain satellite	100.0%	100.0%
Ka band high gain satellite	100.0%	100.0%

Typical 10-15dB achievable link margins still to be compared with the link margins required to meet the (still TBD) performance required for safe flight operation under the influence of time-variant link impairments

Distribution of link margin levels (RPA antenna: AP 7)





Resolution 155 WRC 2019

- **General**

resolves

1 that assignments to stations of geostationary FSS satellite networks operating in the frequency bands 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) in Region 2, 12.2-12.5 GHz (space-to-Earth) in Region 3, 12.5-12.75 GHz (space to-Earth) in Regions 1 and 3 and 19.7-20.2 GHz (space-to-Earth), and in the frequency bands 14-14.47 GHz (Earth-to-space) and 29.5-30.0 GHz (Earth-to-space), may be used for UAS CNPC links in non-segregated airspace*, provided that the conditions specified in *resolves* below are met;

2 that earth stations in motion on board UA may communicate with the space station of a geostationary FSS satellite network operating in the frequency bands listed in *resolves* 1 above, provided that the class of the earth station in motion on board UA is matched with the class of the space station and that other conditions of this Resolution are met (see also *instructs the Director of the Radiocommunication Bureau* 3 below);

3 that the frequency bands specified in *resolves* 1 shall not be used for the UAS CNPC links before the adoption of the relevant international aeronautical standards and recommended practices (SARPs) consistent with Article 37 of the Convention on International Civil Aviation, taking into account *instructs the Director of the Radiocommunication Bureau* 4;

Ku and Ka
FSS Bands

ITU-R Bureau
has created
the UG class

ICAO RPAS Panel
is developing
SARPS



Resolution 155 WRC 2019

• Coordination

resolves

4 that administrations responsible for an FSS network providing UA CNPC links shall apply the relevant provisions of Articles 9 (necessary provisions need to be identified or developed) and 11 for the relevant assignments, including, as appropriate, assignments to the corresponding space station, specific and typical earth station and earth station in motion on board UA, including the request for publication in BR IFIC of items referred to in *resolves* 2 and the course of actions identified in that *resolves* in order to obtain international rights and recognition as specified in Article 8;

9 that the use of assignments of a FSS satellite network for UAS CNPC links shall not constrain other FSS satellite networks during the application of the provisions of Articles 9 and 11;

10 that the introduction of UAS CNPC links shall not result in additional coordination constraints on terrestrial services under Articles 9 and 11;

RPAS/UAS Earth Stations (Air and Ground) are to be coordinated using the same process as other FSS networks and not be given any special status during coordination

Resolution 155 WRC 2019

• Harmful Interference

resolves

13 UAS CNPC links shall:

- ensure that the use of UAS CNPC links be in accordance with the international standards and recommended practices (SARPs) consistent with Article 37 of the Convention on International Civil Aviation;
- take the required measures, consistent with No. 4.10, to ensure freedom from harmful interference to earth stations on board UA operated in accordance with this Resolution;
- act immediately when their attention is drawn to any such harmful interference, as freedom from harmful interference to UAS CNPC links is imperative to ensure their safe operation, taking into account *resolves* 11;
- use assignments associated with the FSS networks for UAS CNPC links (see Figure 1 in Annex 1), including assignments to space stations, specific or typical earth stations and earth stations on board UA (see *resolves* 2), that have been successfully coordinated under Article 9 (including provisions identified in *resolves* 4) and recorded in the Master International Frequency Register (MIFR) with a favorable finding under Article 11, including Nos. 11.31, 11.32 or 11.32A where applicable, and except those assignments that have not successfully completed coordination procedures under No. 11.32 by applying Appendix 5 § 6.d.i;
- ensure that real-time interference monitoring, estimation and prediction of interference risks and planning solutions for potential interference scenarios are addressed by FSS operators and UAS operators with guidance from aviation authorities;

RPAS/UAS C2
Links require
careful
monitoring
and
immediate
action to be
taken to
minimize the
potential for
any safety
effects due
to harmful
interference



Resolution 155 WRC 2019

• Non-RPAS/UAS System Protection

resolves

8 that earth stations of UAS CNPC links of a particular FSS network shall not cause more interference to, or claim more protection from, stations of terrestrial services than specific or typical earth stations of that FSS network as indicated in *resolves* 5 that have been previously coordinated and/or notified under relevant provisions of Articles 9 and 11;

14 that, unless otherwise agreed between the administrations concerned, UA CNPC earth stations shall not cause harmful interference to terrestrial services of other administrations (see also Annex 2);

15 that, in order to implement *resolves* 14 above, power flux-density hard limits need to be developed for UAS CNPC links; one possible example of such provisional limits to protect the fixed service is provided in Annex 2; subject to agreement between the administrations concerned, that annex may be used for the implementation of this Resolution;

16 that the power flux-density hard limits provided in Annex 2 shall be reviewed and, if necessary, revised by the next conference;

17 that, in order to protect the radio astronomy service in the frequency band 14.47-14.5 GHz, administrations operating UAS in accordance with this Resolution in the frequency band 14-14.47 GHz within line-of-sight of radio astronomy stations are urged to take all practicable steps to ensure that the emissions from the UA in the frequency band 14.47-14.5 GHz do not exceed the levels and percentage of data loss given in the most recent versions of Recommendations ITU-R RA.769 and ITU-R RA.1513;

PFD masks are required to protect the terrestrial services, in particular the FS

Out of band emissions also need to be considered



Resolution 155 WRC 2019

- **RPAS/UAS System**

resolves

5 that earth stations of UAS CNPC links shall operate within the notified and recorded technical parameters of the associated satellite network, including specific or typical earth stations of the geostationary FSS satellite network(s) as published by the Radiocommunication Bureau;

6 that earth stations of UAS CNPC links shall not cause more interference to, or claim more protection from, other satellite networks and systems than specific or typical earth stations as indicated in *resolves* 5 as published by the Bureau;

7 that, in order to apply *resolves* 6 above, administrations responsible for the FSS network to be used for UAS CNPC links shall provide the level of interference for the reference assignments of the network used for CNPC links upon request by an administration authorizing the use of UAS CNPC links within its territory;

WP 5B and ICAO are developing C2 Link characteristics to enable:

- 1) WP 5B to analyze compliance with the appropriate Radio Regulations
- 2) ICAO to perform its work on SARPs



Resolution 155 WRC 2019

- **ICAO**

Resolves

11 that earth stations on board UA shall be designed and operated so as to be able to accept the interference caused by terrestrial services operating in conformity with the Radio Regulations in the frequency bands listed in *resolves* 1 without complaints under Article 15;

12 that earth stations on board UA shall be designed and operated so as to be able to operate with interference caused by other satellite networks resulting from application of Articles 9 and 11;

18 to consider the progress obtained by ICAO in the process of preparation of SARPs for UAS CNPC links, to review this Resolution at WRC-23, taking into account the results of the implementation of Resolution 156 (WRC-15), and to take necessary actions as appropriate;

ICAO needs
to consider
harmful
interference
in its SARPs

ICAO should
attempt to
complete its
FSS related
SARPs
amendments
prior to 2023



Anticipated changes to Resolution 155 for WRC-23

- **Clear indication of the regulatory status of UA CNPC assignments within Fixed-Satellite Service Allocations**
 - Make clear that the Earth Stations In Motion (ESIMs) provisions do not apply
- **Elimination of any provisions (in Resolution 155) that are no longer necessary**
- **Recognition of off-axis power limits that apply to Ku and Ka band transmissions from the RPA**
- **Finalization of a PFD mask for protecting terrestrial services**
- **Clear identification of administration responsibilities**
 - Including requirements to prevent harmful interference and use coordinated assignments
- **Clear identification of ITU-R Radiocommunication Bureau actions**
- **Retention of the existing priority date of protection for UA CNPC assignments**
- **Restructuring and organizing the provisions to make them easier to understand**



ICAO Position and WRC-23 desired outcome

- ICAO Secretary General letter (August 2021) to all member States

Action required: To consider the ICAO Position when developing your State's position for WRC-23 and to support the ICAO Position during WRC-23

Items for which aviation is seeking an action for WRC-23 include:

- c) appropriate regulatory actions, with a view to reviewing and, if necessary, revising Resolution 155 to accommodate the use of fixed-satellite service (FSS) networks by RPAS C2 Links (Agenda Item 1.8);
- ICAO FSS specific SARPs provide for safe operation in the absence of an ITU-R AMS(R)S allocation
- The FSS is a mature ready to use service with global coverage and enough spectrum to support RPAS operations well into the future

To support ITU-R studies, as called for by Resolutions 155 (Rev.WRC-19) and 171 (WRC-19).

To support the modification of No. 5.484B and Resolution 155 (Rev.WRC-19).

ICAO is expecting that the decision of WRC-23 will result in a Resolution that:

- clearly provides primary status;
- removes any apparent inconsistencies;
- acknowledges that in accordance with the Annexes of the Convention of the International Civil Aviation Organization (ICAO), ensuring the safety-of-life aspects of the use of UAS CNPC is the role of the responsible States;
- provides sufficient information to support and/or validate safety cases; and
- ensures that safety cases do not need to be revisited as a result of future satellite co-ordination agreements.

ICAO position being finalized by FSMP



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THANK YOU