# Report ITU-R RA.2551-0 (03/2025)

RA Series: Radio astronomy

# Harmonics-related unwanted emissions in radio astronomy bands: measurement of impacts of harmonic emission at radio astronomy facilities



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# REPORT ITU-R RA.2551-0

# Harmonics-related unwanted emissions in radio astronomy bands: measurement of impacts of harmonic emission at radio astronomy facilities

(Question ITU-R 145-3/7)

(2025)

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# 1 Introduction

Radio astronomy provides a valuable window for scientists to study our universe. Radio astronomy has been used to make many advances in astronomy, including creating the first maps of our Galaxy, providing evidence for dark matter, measuring the expansion rate and geometry of the Universe, and generating the first image of the region immediately around a black hole. The critical scientific research undertaken by Radio Astronomy Service (RAS) requires access to interference-free bands.

The emissions that radio astronomers detect from the cosmos are extremely weak and radio astronomy receivers are designed to pick up such remarkably weak signals, therefore radio observatories are particularly vulnerable to interference from in-band emissions, spurious and out-ofband emissions from licensed and unlicensed users of neighbouring bands, and emissions that produce spurious harmonic signals into the radio astronomy bands, even if those human-made emissions are weak and distant. In other words, as a passive (receive-only) service, RAS stations require an environment that is as free of human-made emissions as possible in order to make accurate scientific measurements of faint, naturally occurring cosmic signals.

Of particular value are the frequency bands where Radio Regulations (RR) No. **5.340** applies, which lists frequency bands in which "all emissions are prohibited". However, as illustrated in this Report and other ITU-R documents (e.g. Reports ITU-R RS.2490, ITU-R RS.2491, and ITU-R RS.2492), despite this designation, observations and measurements by the passive science services in the RR No. **5.340** bands still detect anthropogenic radio emissions. When interference is detected in these bands, it is necessary to identify the sources of emission to be remediated, including those generated by harmonics and other spurious emissions, to ensure interference-free measurements by RAS stations.

Administrations are urged, as far as practicable, to take into consideration the need to avoid spurious emissions which could cause interference to radio astronomy operating in accordance with RR Article **29**. Radio Regulations No. **29.8** states "The status of the radio astronomy service in the various frequency bands is specified in the Table of Frequency Allocations (Article **5**). Administrations shall provide protection from interference to stations in the radio astronomy service in accordance with the status of this service in those bands (see also RR Nos. **4.6**, **22.22** to **22.24** and **22.25**)".

Information on the levels of interference detrimental to the RAS is given in Recommendation ITU-R RA.769-2. Recommendation ITU-R RA.611 provides more information on the protection of the RAS from spurious emission. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products. This document will focus on the impact of harmonics emissions on the RAS.

This Report describes how different parameters can influence the effect of harmonic emissions from transmitters into RAS bands and documents measurements of emissions in frequency bands allocated to the RAS, including those that are listed in RR No. **5.340**, which can be identified as being spurious harmonic emissions.

# 1.1 Harmonic emissions

Harmonic emissions are a class of spurious emissions created by emitters at integer multiples of the central frequency of emission. For example, transmitters operating at 711.25 MHz or transmitters operating at 466.7-475.7 MHz may unintentionally create spurious 2<sup>nd</sup> or 3<sup>rd</sup> harmonic emission in the middle of the 1 400-1 427 MHz band allocated to radio astronomy, which includes the signal of neutral hydrogen atoms which emit at a rest frequency of 1 420 MHz and have been used to map the structure of our Galaxy. For passive services, like radio astronomy, which seek to detect very faint cosmic signals with frequencies defined by the physics of atoms and molecules, harmonic emission into these bands may have a catastrophic impact on the ability to observe.

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Question ITU-R 145-3/7 *decides* 4 calls for the study of ways radio astronomy observations are affected by spurious and out-of-band emissions from radio transmitters located in other frequency bands. This Report specifically considers harmonic emissions which may interfere with passive observations, particularly in the RR No. **5.340** bands. As guidance for practical purposes, Table 1 of Recommendation ITU-R SM.329-12 (reproduced here as Table 1 below) gives the frequency ranges to be considered when measuring spurious emissions, including harmonics.

#### TABLE 1

#### Frequency range for measurement of unwanted emissions (Table 1 from Rec. ITU-R SM.329)

Fundamental frequency range	Frequency range for measurements		
	Lower limit	Upper limit (The test should include the entire harmonic band and not be truncated at the precise upper frequency limit stated)	
9 kHz – 100 MHz	9 kHz	1 GHz	
100 MHz – 300 MHz	9 kHz	10 <sup>th</sup> harmonic	
300 MHz – 600 MHz	30 MHz	3 GHz	
600 MHz – 5.2 GHz	30 MHz	5 <sup>th</sup> harmonic	
5.2 GHz – 13 GHz	30 MHz	26 GHz	
13 GHz – 150 GHz	30 MHz	2 <sup>nd</sup> harmonic	
150 GHz – 300 GHz	30 MHz	300 GHz	

Radio Regulations No. **1.145** states the "Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions".

Appendix **3** to the RR indicates the maximum permitted power levels for unwanted emissions in the spurious domain. It also states that "For technical or operational reasons, more stringent levels than those specified may be applied to protect specific services in certain frequency bands". And that: "special consideration of transmitter spurious domain emissions may be required for the protection of safety services, radio astronomy and space services using passive sensors". RR No. **29.11** states: "When assigning frequencies to stations in other bands, administrations are urged, as far as practicable, to take into consideration the need to avoid spurious emissions which could cause harmful interference to the radio astronomy service operating in accordance with these Regulations (see also RR No. **4.6**)."

The issue of the 2<sup>nd</sup> harmonics is also addressed in RR No. **5.402**, stating: "The use of the band 2 483.5-2 500 MHz by the mobile-satellite and the radiodetermination-satellite services is subject to the coordination under RR No. **9.11A**. Administrations are urged to take all practicable steps to prevent harmful interference to the radio astronomy service from emissions in the 2 483.5-2 500 MHz band, especially those caused by second-harmonic radiation that would fall into the 4 990-5 000 MHz band allocated to the radio astronomy service worldwide".

### **1.2** Design considerations

A common cause, but not the only cause, of harmonic emission is non-linearity in the transmitter stages, in particular in the final power amplifier stage. Any non-linearity will generate harmonics, but a particularly common form of non-linearity is slight gain compression in one or more of the transmitter stages. In the extreme case, a pure sine wave at the transmitter output could be distorted into a waveform resembling a square wave, which contains an abundance of odd harmonics. However, any distortion of the waveform will generate harmonics. In practice all transmitters generate some level of harmonic emission, but filters at the output of the transmitter can be used to reduce the harmonic emission. RR No. **1.145** also refers to spurious emissions as: "*Emission* on a frequency or frequencies which are outside the *necessary bandwidth* and the level of which may be reduced without affecting the corresponding transmission of information".

In some cases, additional harmonic protection may be obtained without additional expense, just by shaping the transmitter antenna<sup>1</sup>. A signal with an integer fraction of the carrier wavelengths usually "fits" as well into the geometry as the desired signal. (Based on similar considerations, one can also make a similar argument for intermodulation products.) By playing with the geometry of the antennas, it is thus possible to modify the behaviour. For example, one could put holes into a patch antenna, which would significantly attenuate the particular harmonics related to the associated length scale. However, it is not possible to eliminate all harmonics in this manner, as one would need literally infinitely many holes in the patch antenna. Still, with careful antenna design, which is mindful of the spectrum regulatory environment, particularly vulnerable victim services could be protected from certain spurious features without major drawbacks for the vendors such as much increased costs.

# 1.3 Challenges and opportunity cost to RAS

Radio frequency interference (RFI) has the potential to corrupt scientific data, leading to loss of information and the potential for incorrect analysis and conclusions. Thus, methods to identify and mitigate sources of radio frequency interference are critical to enable reliable and accurate scientific measurements throughout the radio spectrum.

The cost to RAS of RFI identification and mitigation includes not only the physical and personnel resources to monitor, track, and identify sources of interference, but also the loss of data corrupted by the interference. In some cases, RFI is strong enough so that corrupted data can be flagged and excised through automated data analysis tools. However, effective use of such tools requires high data rates to have sufficient sampling in both spectral and time dimensions, resulting in the need for additional data storage capacity and computational resources for data analysis<sup>2</sup>. Furthermore, data excision results in loss of data, which is costly. Specifically, if it is even possible to re-do the observations, additional telescope time is required to replace data lost due to excision of radio frequency interference, which has both financial and opportunity costs. Apart from the cost, lost time may be irreplaceable in the case of time-variable astronomical phenomena.

Many RAS facilities run campaigns to identify and locate the origin of a spurious RFI signal, which was detected during an astronomical observation. Usually this involves several people who use dedicated spectrum monitoring equipment searching in the environment of the RAS station with directional (hand-held) antennas. This is a labour-intensive process, which is not successful in all cases. Intermittent interfering signals are especially hard to track down. If the source is on private

<sup>&</sup>lt;sup>1</sup> W. Li, P. Li, J. Zhou and Q. H. Liu, "Control of Higher Order Harmonics and Spurious Modes for Microstrip Patch Antennas," in *IEEE Access*, vol. 6, pp. 34158-34165, 2018, doi: 10.1109/ACCESS.2018.2850858.

<sup>&</sup>lt;sup>2</sup> As an example of the kind of analysis needed, we refer to Sheikh, S. et al. "Analysis of the Breakthrough Listen signal of interest blc1 with a technosignature verification framework" in Nature Astronomy, vol. 5, pp. 1153-1162, 2021, doi: <u>10.1038/s41550-021-01508-8</u>.

premises, RAS staff in some countries may not be able to continue the search. However, in several countries, network agencies have the right to enter private land to find sources of harmful interference.

Equipment capable of spectrum monitoring, in particular high-quality spectrum analysers are costly. However, this is considered a good investment in the long run by many RAS facilities. Efficiency could be improved by using standardized equipment and common data formats and analysis software, which is not yet common practice. In addition, radio telescopes have a large gain and long integrations may be performed to detect weak cosmic signals. Therefore, there can be cases where the signal can only be detected with the highly sensitive RAS receiving system but not with monitoring equipment. If the RAS antenna is used to identify interfering sources, then it usually cannot perform astronomical observations at the same time. Likewise, the personnel involved in tracking RFI cannot work on science when doing RFI measurement campaigns.

While bright signals create the most obvious problems, low levels of interference are much more difficult to identify and may affect measurements without any clear indication that they are corrupted. RFI mitigation strategies that rely on excision of corrupted data are not sufficient to ameliorate data affected by this kind of interference and the identification of the source of interference will be even more difficult (i.e. costly), particularly if the source is intermittent or mobile. This type of weak radio frequency interference may be mistaken as natural emissions and lead to incorrect analysis and incorrect scientific results. In the latter case, this can be damaging to scientific progress and result in a significant waste of resources, specifically in regard to follow-up observations and the time invested in identifying the issue.

Such sources of low-level radio frequency interference may arise from harmonic or spurious emissions generated by low-cost devices produced without sufficient attention to antenna design or appropriate bandpass filters. In all cases, data lost to radio frequency interference is data lost to science.

The ITU Handbook on radio astronomy includes a section (section 6.4.3.3 starting on p. 88) describing some potential cases of harmonic interference from satellites. For example, the Handbook describes how broadcasting satellites with an allocation at 11.7-12.5 GHz may have 2<sup>nd</sup> harmonics which overlap with the 23.6-24.0 GHz RAS band (an RR No. 5.340 band), which contains spectral lines from ammonia (NH<sub>3</sub>) at 23.694, 23.723 and 23.877 GHz important to RAS. The fixed-satellite service (FSS) has an allocation at 10.7-12.2 GHz, with second harmonics overlapping the RAS band 22.21-22.5 GHz, this RAS band contains a spectral line from water vapour (and is noted in RR No. 5.149) which might help with astronomers wish to understand the frequency of life in the universe. Similarly, space-earth transmissions allocated in both 7.55-7.75 GHz and 81-84 GHz have 2<sup>nd</sup> harmonics overlapping RAS bands important to allow for a widely separated frequency measurements of continuum emission from radio astronomy objects (15.35-15.4 GHz in RR No. 5.340 – except those provided for by No. 5.511 – and 164-168 GHz in RR No. 5.340). Downlinks from radiodetermination satellite and mobile satellite services allocated to 2 483.5-2 500 MHz have a second harmonic in the 4 990-5 000 MHz RAS band (which is in RR No. 5.149). Meteorological satellite service (downlink) allocated to 460-470 MHz could have third harmonic emission in the 1 400-1 427 MHz band (RR No. 5.340) which brackets the astronomically significant 1 420.406 MHz line from neutral hydrogen.

### **1.4** Influence dependency with different parameters

Normally, harmonic emissions from radiocommunication stations are low level compared to their main emissions. To understand how different parameters can affect the total received power at a radio astronomy station a simple assessment is used here, using a particular RAS station as an example. Important parameters to consider could vary from those which contribute directly, such as transmitter power or transmitter/receiver gains, to those contributing indirectly, such as receiver height or terrain profile. Considering the difficulties with correlating harmonic emissions of a transmitter with actual

measurements conducted with a radio telescope (as discussed in § 2), it is helpful to assess how different parameters' influence these scenarios.

# **1.4.1** Transmitter height

Transmitter and receiver heights are one of the common parameters that are required to use the radio wave propagation models (e.g. one in Recommendation ITU-R P.452).

To assess the impact of transmitter height, the following fixed parameters were used:

- Frequency: 1.4 GHz
- Protection limits based on Recommendation ITU-R RA.769:
  - Continuum mode: -278.84 dB(W / Hz)
  - Spectroscopy mode is -263.19 dB(W / Hz)
  - Time percentage: 2%
- Receiver location: SKA-Mid radio telescope site, near to the centre of radio quiet zone in Republic of South Africa:
  - Latitude: 30°42'47" S
  - Longitude: 21°26'38" E
- Weather parameters:
  - Temperature: 290K
  - Pressure: 101.3 kPa
- Transmitter power density: -60 dBW/MHz (-30 dBm/MHz)
- Receiver and transmitter antennas were considered to be isotropic for this scenario.

In this scenario the minimum coupling loss is -158.84 dB for continuum mode and -143.19 dB for spectroscopy mode.

For three different transmitter heights that could be seen as typical of land-based transmitters the exclusion zone is almost similar, showing strong terrain profile impact and can be seen as being within a range of national borders. This could be seen in Fig. 1, where both exclusion zones for continuum (yellow area with cyan border) and spectroscopy (red area with black border, includes continuum) modes stay similar with transmitter height changing from 6 to 100 metres.

#### FIGURE 1

Exclusion zones to protect RAS observations in continuum (cyan) and spectroscopy (red) modes for transmitter heights of 6, 35 and 100 m



a) Tx height: 6 m





b) Tx height: 35 m

6

c) Tx height: 100 m

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This means that an RAS site may benefit from the natural shielding surrounding the area. However, for transmitter heights that could be seen as airborne based transmitters, the situation changes significantly. This can be seen in Fig. 2, where exclusion zones grow rapidly with transmitter height changing from 10 to 50 km.

#### FIGURE 2 Exclusion zones to protect RAS observations in continuum (cyan) and spectroscopy (red) modes for transmitter heights of 10, 20 and 50 km



a) Tx height: 10 km

- b) Tx height: 20 km
- c) Tx height: 50 km

It could be seen that in some cases the exclusion zone takes the shape of a circle. This could be due to lack of path profile related attenuation. Exclusion zones are becoming bigger and reach areas beyond the national borders, which might raise the level of this issue from a national one to, at least, requiring bilateral agreements with neighbouring countries.

This assessment leads to the conclusion that an increase in transmitter height might lead to interference at RAS stations, much like that caused by airborne transmitters. While in the past lower height transmitters allowed exclusion zones to be confined within national borders, transmitters at higher altitudes makes it important to study this parameter. Thus, much as in the case of airborne or spaceborne transmitters, attenuation due to the terrain may not be sufficient.

### 1.4.2 Receiving antenna pointing and gain

While impact assessment between RAS stations and terrestrial transmitters are conducted considering 0 dBi as receiver antenna gain as recommended by Recommendation ITU-R RA.769, it is also mentioned that RAS stations have a considerable gain in the forward direction and for situations with transmitters near the boresight of the antenna it needs to be considered. A typical RAS station antenna pattern can be found in Recommendation ITU-R RA.1631 and is shown in Fig. 3 at 1 413.5 MHz and for different antenna diameters.

#### FIGURE 3





Radio astronomy antennas usually have very high gains (for example, more than 40 dB at 1 413.5 MHz for dish antennas bigger than 13.5 m) to be able to observe distant faint signals of cosmic origin. In the case of a high-altitude transmitter (e.g. airborne or spaceborne ones), an RAS antenna pointing directly to it will receive a very strong power even with relatively low emissions levels. Due to this, sources within approximately 10-degree cone would provide significant part of received interference.

### 2 Measurement of impacts of harmonic emission at radio astronomy facilities

#### 2.1 Techniques to identify harmonics emissions

Techniques which can be used to identify as signal as a harmonic of a primary transmission, include:

- Simultaneous or asynchronous measurement of the primary signal demonstrating a similar frequency pattern, for example if the fundamental frequency drifts, the harmonics should drift at n times the rate (where n is the harmonic number). Furthermore, the spectral shape of the harmonics signal can sometimes appear similar to the primary signal.
- Simultaneous measurement of the primary signal demonstrating a similar pattern of time dependence.
- If control of the primary transmission is possible, turning it on and off to see if the suspected harmonic disappears and reappears accordingly.
- Decoding the signal that is intentionally being transmitted at the fundamental frequency from the harmonic emission, for example in the case of terrestrial radio services, connecting a household radio receiver to the suspected harmonics to see if the station being transmitted can be heard.

As it can be difficult to identify the source of an interfering signal, it would be useful to RAS facilities to have access to a list of frequencies of possible harmonics generated by common devices which would fall into RAS bands.

Another issue is that harmonics (even ones, especially) can be generated in the front end of receivers if they are being driven into compression or saturation by a strong signal at the fundamental frequency. Expensive spectrum analysers have extensive dynamic range, but this is not usually the case for low-cost devices. If harmonics are being locally generated by a strong fundamental, the solution is to reject the fundamental with a good bandpass filter, for example a cut-off waveguide.

This is already implemented at most/many RAS facilities, but should be confirmed in all measurements.

It is usually desirable to detect any candidate interfering signal not just with the radio telescope receiving system but also with a dedicated and well-calibrated spectrum monitoring device. This is usually necessary to make a calibrated measurement of received power flux density (or even transmitted spectral power, if the distance to the source is known) for regulatory processes. Such a measurement is often impossible with the radio telescope receiving system which is designed to measure incoming cosmic radiation, and thus may have unknown gain for near-field sources. In many countries, administrations offer to assist with follow-up measurements, providing a solution for RAS facilities without appropriate monitoring equipment.

# 2.2 United States of America

### 2.2.1 Arecibo Observatory, Puerto Rico

In October 2003, a test was done in collaboration with TV Channel 54 to look for impacts into passive radio astronomy bands at Arecibo Observatory. The broadcasting video channel emits its primary signal at 711.25 MHz. The 2<sup>nd</sup> harmonic of this frequency falls at 1 422.5 MHz in the RAS allocated 1 420-1 427 MHz band which is listed in RR No. **5.340**.

A member of staff at the 711.25 MHz transmitter site opened and closed the transmitter doors and turned the transmitter on and off while the Arecibo Radio Telescope was taking data. The Arecibo Telescope L-band wide receiver, sensitive to emission in the 1 420-1 427 MHz band, was used in circular polarization mode. Data was taken with the interim correlator running in two modes: 381 Hz and 95 Hz resolution. Data was saved once a second.

The results of this experiment are shown in Fig. 4, which shows (upper panel) a second harmonic (1 422.50 MHz) signal present when the transmitter doors were open, significantly weaker (middle panel) when they were closed, and absent (lower panel) when the transmitter is turned off. The time variation, along with the frequency at exactly twice that of the 711.25 MHz fundamental frequency uniquely identifies the signal as a spurious second harmonic of the 711.25 MHz signal.







*Note to Fig. 4:* The vertical scale is given as a fraction of system noise Tsys, which corresponds to -158 dBm per resolution bandwidth, at the input to the receiver.

As another example of harmonic emission, in October 2005, signals were detected by the Arecibo Telescope with frequencies consistent with third harmonics of four local FM radio stations (FM 102.9, 104.1, 106.5 and 107.3). The third harmonic of the FM 107.3 radio station was measured to peak at 321.9 MHz and spread into the 322-328 MHz RAS band which is listed under RR No. **5.149** (see Fig. 5; typical levels of frequency modulation for FM radio cause this 3<sup>rd</sup> harmonic to cross the 322 MHz band edge). Signals at 321.9 and 319.5 MHz were still present when bandpass filters were placed around the receiver to exclude out of band emissions, confirming they were generated outside of the receiver. Identification as harmonics of the radio stations was confirmed by passing the 3<sup>rd</sup> harmonics frequencies through a household radio receiver – the signal from the FM 107.3 and FM 104.1 stations was audible at their 3<sup>rd</sup> harmonics peaking at 321.9 MHz and 312.3 MHz.





*Note to Fig. 5:* Each colour represents a different sweep in azimuth, the plot shows the maximum system temperature recorded during the sweep. The third harmonic frequencies of several local FM radio stations are shown by vertical dashed lines.

### 2.2.2 The very large array, New Mexico

During the filming of the movie "Contact" at the Very Large Array (VLA) in New Mexico in September/October 1996, unusual signals were noticed when a hand-held radio was being used on site. Subsequent measurements on site made use of a spectrum analyser fitted with a filter with a 1-2 GHz frequency bandpass to exclude the primary signal from the hand-held radio at 162.025 MHz. Harmonics 6, 7, 8, 9, 10 and 11 (at 972.15, 1 134.175, 1 296.2, 1 458.225, 1 620.5 and 1 782.275 MHz respectively) were detected at Pm values of -74, -76, -69, -60, -75 and -76 dBm. The power levels measured in the harmonic near to 1 400 MHz from this device caused its use to be discontinued on site to reduce background noise in the L-band receiver at the VLA.

In November 2005, the United States National Radio Astronomy Observatory (NRAO) staff measured several harmonics generated as spurious emission from a VoIP phone in the base of a VLA antenna and suggested necessary shielding needed at each VLA antenna of 75-80 dB to allow them to observe without unacceptable levels of interference with their phone on. Multiple harmonic frequencies were measured at the input of the receiver to be -115 to -140 dBm with most found to be at -130 dBm. This measurement is reported in an NRAO memo dated January 2006 (EVLAM99<sup>3</sup>). Figure 6 shows the spectrum measured from various different VoIP systems.

<sup>&</sup>lt;sup>3</sup> <u>https://library.nrao.edu/public/memos/evla/EVLAM\_99.pdf</u>





*Note to Fig. 6:* Resolution is 1 kHz for Systems 1-3 and 100 kHz for System 4. MC = 'media converter unit'. This region of spectrum includes numerous RAS primary or secondary allocations (1 400-1 427 MHz, 1 610.60-1 613.80 MHz, 1 660-1 670 MHz and 1 718.80-1 722.20 MHz) as well as the 5.139 region 1 330-1 400 MHz.

EVLA uses a reference signal at 128 MHz as a clock signal for Field Programable Gate Arrays (FPGA) used in various electronics. Reports of interference at 1 408 MHz (the  $11^{th}$  harmonics of 128 MHz) led to a search for harmonics and the identification of the 128 MHz reference signal from some of the electronics as the generator of a variety of odd harmonics (e.g. both 1 408 MHz, and 1 920 MHz – the  $15^{th}$  harmonics were detected in interference scans done in 2013 and 2014). While the  $11^{th}$  harmonic is beyond the range for measurements of spurious emissions in Recommendation ITU-R SM.329 (see Table 1) it is a distinctive and well recognized interference feature at the VLA.

An NRAO memo (EVLAM183<sup>4</sup>) reported these finding along with additional testing of spurious emissions from various internal electronics with FPGA, recommending that some of the equipment needed additional shielding to minimize the impact of the harmonic emissions on RAS observations.

# 2.2.3 Owens Valley Radio Observatory, California

Data were taken in February 2021 using the DSA-100 (the 100-element Deep Synoptic Array) currently being developed at the Owens Valley Radio Observatory (OVRO) to monitor emissions in the 1 420-1 427 MHz RAS passive band. Investigation is ongoing to seek the source of several narrow band signals which were detected (see Fig. 7).

FIGURE 7 Data taken in February 2021 with the DSA-100 currently being developed at the Owens Valley Radio Observatory (data provided by the California Institute of Technology)



<sup>13</sup> 

<sup>&</sup>lt;sup>4</sup> <u>https://library.nrao.edu/public/memos/evla/EVLAM\_183.pdf</u>



# 2.3 Other regions

# 2.3.1 South Pole telescope

The South Pole Telescope (SPT) is a 10 m diameter telescope primarily used for observations of the cosmic microwave background (CMB) designed to operate at microwave frequencies (with bands centred at 95, 150 and 220 GHz) from the United States Research Station (the Amundsen-Scott South Pole Station), located in the South Pole Antarctic Treaty Area.

In November 2020, SPT reported observations of a bright non-thermal point source moving across their field of view. After discussions with the satellite operator, it was determined that the emissions detected by SPT were the 6th and 9th harmonics of the satellite's K-band antenna. These harmonic frequencies of 24.52 GHz overlap with the 150 GHz and 220 GHz observing bands of the SPT telescope. Notably, the 6th harmonic of 24.52 GHz is at 147 GHz, which is within the 136-148.5 GHz band, listed in RR No. **5.149**.

# 3 Summary

This Report describes how harmonic emissions may affect radio astronomy facilities in bands allocated to radio astronomy in particular when transmitting stations are at high altitude, and provides several examples of harmonic emissions detected by RAS stations. In some cases, these emissions are found in passive RAS bands mentioned in RR No. **5.340** or RR No. **5.149**. The Report begins with some background information on harmonic emissions, a class of spurious emissions found at integer multiples of the primary transmission frequency, the amplitude of which depends on the design of the transmitting device. It also lists the challenges that harmonics emissions, on large scale removal of data flagged with strong RFI, and the problems of identifying weaker interference and distinguishing it from natural cosmic emissions. A section on measurements provides advice on techniques to identify harmonics emission, which can be challenging to distinguish from other sources. Finally, several examples of harmonics signals detected at radio astronomy facilities are given. The above examples illustrate the potential impact of harmonics at radio astronomy facilities.

According to the measurement results and parameter assessment, it is possible to conclude that harmonics emissions might create a risk of interference to the radio astronomy stations in specific

scenarios and under specific conditions, in particular when the transmitter is at high altitudes. While harmonic emissions from terrestrial transmitters is normally a national matter (due to terrain shielding and propagation losses), the same effect from air and space borne transmitters can be an international matter as shown in this Report. Further case-by-case studies might help determining whether harmonics effects should be taken into account or not.

### 4 References and related ITU-R Recommendations and Reports

Recommendation ITU-R SM.329 - Unwanted emissions in the spurious domain

Recommendation ITU-R RA.769 – Protection criteria used for radio astronomical measurements

- Recommendation ITU-R SM.1540 Unwanted emissions in the out-of-band domain falling into adjacent allocated bands
- Recommendation ITU-R SM.1541 Unwanted emissions in the out-of-band domain

Recommendation ITU-R SM.1542 - The protection of passive services from unwanted emissions

- Recommendation ITU-R SM.1633 Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands
- Report ITU-R RA.2259 Characteristics of radio quiet zones
- Report ITU-R RS.2490 Global survey of radio frequency interference observed by the Aquarius scatterometer in the 1 215-1 300 MHz band and the Aquarius radiometer in the 1 400-1 427 MHz band
- Report ITU-R RS.2491 Global survey of radio frequency interference observed by the SMAP radar in the 1 215-1 300 MHz band and the SMAP radiometer in the 1 400-1 427 MHz band
- Report ITU-R RS.2492 Global survey of radio frequency interference observed by SMOS radiometer in the EESS (passive) band 1 400-1 427 MHz

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### 5 List of acronyms and abbreviations

- CMB Cosmic microwave background
- DSA Deep synoptic array
- FPGA Field programable gate arrays
- GPS Global positioning system
- NRAO United States national radio astronomy observatory
- NTIA (US) National telecommunications and information administration
- OVRO Owens valley radio observatory
- RAS Radio astronomy service
- RFI Radio frequency interference
- SPT South pole telescope
- VLA Very large array