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ADS-B Performance Monitoring and Potential Electromagnetic Interference

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***Abstract*—The integration of unmanned aircraft systems (UAS) into the air traffic management will be very demanding. Surveillance equipments based on Automatic Dependent Surveillance-Broadcast (ADS-B) contribute a significant role for maintaining separations between both UAS and aircraft in order to maintain the requirements of aviation safety and airspace integrity. Performance analysis of ADS-B equipments related to signal quality and potential Electromagnetic/Radio Frequency Interference is very important to mitigate the failure risk in air traffic management. This paper discuss performance test analysis of ADS-B based surveillance equipments related to the most importance performance parameter namely the continuous reception of messages in terms of message drops and probability of update interval message receptions. Another performance test related to electromagnetic emission of ADS-B based surveillance equipments is conducted in order to mitigate potential RF interferences.**

***Index Terms*—ADS-B, electromagnetic, performance test, Radio Frequency Interference (RFI), signal quality, surveillance, traffic management**

I. Introduction

Data received from ADS-B based surveillance equipments complement the coverage of radar data especially in areas where radar is not available (non-radar area). ADS-B data has a higher refresh rate of target (>1s) compare to radar. ADS-B data consists of navigational data such as position, velocity, time and integrity level. Secondary Surveillance Radar (SSR) is classified as a co-operative independent surveillance system. Aircraft replies SSR interrogating signal to the ground station (co-operative) and SSR ground station determines the aircraft range and azimuth with respect to the radar antenna (independent). Primary Surveillance Radar (PSR) is classified as a non-cooperative (no reply from aircraft) independent (ground station determine the aircraft range and azimuth based on the reflected PSR signal) surveillance system. In ADS-B system, the aircraft determine their own state (dependent) and the aircraft broadcast its position information to the ground station and the nearby aircrafts (co-operative). Therefore ADS-B is classified as a co-operative dependent surveillance system. The information of aircraft position is determined using GNSS (Global Navigation Satellite System).

Surveillance data received by ground stations is analyzed for data quality and signal quality in terms of latency and accuracy. Latency of surveillance data can be estimated by comparing the target (on-board reference) timestamps and the ground station timestamps. The accuracy of surveillance data can be calculated by having the root mean square and the average of the position offsets. The horizontal offset is determined as [1]:

$$d = (RE + h) \cdot \arccos(\sin \varphi 1 \sin \varphi 2 + \cos \varphi 1 \cos \varphi 2 \cos \Delta\lambda) \quad (1)$$

with:

RE = the radius of the Earth

h = the altitude of the aircraft

φ = the latitude of the aircraft

λ = the longitude of the aircraft

Surveillance signal received by ground station is analyzed for signal quality in terms of update interval and integrity. The update interval of surveillance signal is the time interval between succeeding position messages received by ADS-B receiver. The time interval is calculated based on the timestamps from succeeding position messages received from a specific aircraft. This update interval relates closely to the reception probability. Reception probability may drop due to frequency congestion since ADS-B frequeny is also used for SSR. In addition, reception probability may also drop due to increasing traffic density and the type of ADS-B receivers. Integrity of surveillance signal is related to an indicator in the ADS-B message version 1 and 2 as NIC (Navigational Integrity Category). This NIC values present the Horizontal Position Limit (HPL). In En-route the acceptable NIC values must be higher or equal to 5. In approaching phase the acceptable NIC values must be higher or equal to 7 [7][8] .

ADS-B becomes an enabler to improve surveillance data and signal quality in some non-radar areas. ADS-B data provides a better situational awareness for the pilot and better airborne separation applications. However, there is a necessity to improve the data and signal quality of ADS-B itself to ensure that a sufficient level of surveillance quality is satisfactory.

Therefore many studies have been performed to investigate the quality of ADS-B data and signal. In [1] an analysis of a large data set of raw ADS-B messages received by ground station has been described to investigate the quality of ADS-B. Results of this paper have shown that the aircraft are able to accurately report their navigational information, but reception probability and malfunctioning on-board equipment may decrease the quality of ADS-B signals. There are some foundings in this paper such as the corrupted ADS-B timestamps due to faulty in the time synchronization with UTC time. Update interval for position updates varies between 0.4 and 0.6 seconds. In the edge of coverage area the update interval increases due to poor reception from aircraft. But still the update interval is lower than the radar update interval (4seconds).

In [2] a study related to the use of ADS-B for Small Unmanned Aircraft Systems (SUAS) in a high density area and or near airport, in relation to separation with General Aviation (GA) which typically under 500 feet (ft) above ground level (AGL). The increase number of SUAS may result in a higher airspace traffic density with a large number of ADS-B. Results from this paper show that co-channel interference may impact GA aircraft ADS-B air to air performance negatively. While SUAS was not affected by the presence of GA aircraft, means that lower SUAS transmit power is recommended to reduce co-channel interference.

In [3] other types of surveillance equipments are evaluated for their surveillance quality. In the upcoming Communication Navigation Surveillance/Air Traffic Management (CNS/ATM), various types of surveillance sensors such as Ground Based Augmentation System (GBAS), Multi Lateration (MLAT) sensors and Wide Area Multilateration (WAM) are necessary to be fusioned in order to get a higher quality of surveillance data. Table 1 summarizes differences of SSR, WAMLAT and ADS-B.

In [4] security mechanisms to protect surveillance data using encoder-decoder algorithm is used which may detect illegitimate message as 4.3% of all datasets.

TABLE I. PERFORMANCE OF SSR, WAMLAT AND ADS-B [3]

	SSR	WAMLAT	ADS-B
Position fix-type	Time of Reception	Time Difference of Arrival	GNSS fix
Accuracy (at 90, 120 nm)	450,600 metres	30,60 metres	20,20 metres
Cost of Fitment	Nil cost	Nil cost	Cost involved
Potential for Global Coverage	No	No	Yes
Capacity increase	No	Potential	Yes
Aircraft to aircraft	No	No	Yes
Separation assurance	No	No	Yes
Aircraft intent	No	No	Yes

There are many parameters for the assessment of ADS-B performance, but this paper analyses only the signal quality in terms of update intervals, reception probability and electromagnetic radiated emission from various ADS-B surveillance equipment. The results of this test analysis provides an overview of the performance of ADS-B receivers and may be used as a reference for further study in a real observation ADS-B data instead of the generated RASS signal, a longer period of ADS-B data collection, and a more products testing for Radiated Emissions.

II. METHODOLOGY

This paper discusses merely the analysis of received surveillance signal in the signal quality aspects, by performing testing as follows:

1. Update intervals of the received surveillance signal from a RASS (Radar Field Analyser RFA 641) signal generator which simulates ADS-B Message DF-18.
2. Reception probability of the received position messages during the data collection period 15 August 2018
3. Electromagnetic Radiated Emission from several ADS-B receivers referring CISPR 22 product standards.

III. VULNERABILITY OF ADS-B SYSTEM

In [5][14] several critical elements that may cause decrease in data and signal quality of ADS-B system are discussed. The critical elements are:

1. GNSS data: Intentional threads (jammer, spoofing) and unintentional threads (ionospheric, GNSS satellites , RFI from: Mobile satellite service, VHF transmitter, Information

Telecommunication Equipments, UWB radar, Digital TV broadcast)

2. Transmitter in the aircraft:
    a. Aircraft Navigational Sensors (GNSS):
    b. ADS-B transmitter (Intentional Threads: System Turn Off, Unlawful RFI)
3. Receiver in the aircraft:
    a. ADS-B receiver
    b. Surveillance Data processing
4. Ground Station:
    a. ATC display
    b. ATC processing system
    c. ADS-B receiver
    d. Traffic broadcast
5. Propagation Path (Intentional Threads: Spoofing, Jamming, RFI, Delayed message; unintentional threads: multipath, RFI)

The critical elements of ADS-B system are mostly from the ADS-B transmitter/receiver and the performance of GNSS. Performance of GNSS is discussed with their potential interference sources [15]. In addition, one of surveillance system which is based on ADS-B data is Advanced Surface Movement Guidance and Control System (A-SMGCS). A-SMGCS is an airport system used to improve the efficiency of the use of runway by increasing the capacity of runways while maintaining the required level of security]16]. One of the performance parameter of A-SMGCS is the Probabillity of Target Report (PTR) on the Surveillance output. This PTR value must be greater than or equal to 95% in the area of maneuver with the rate of renewal of data at least in one second [6, 16]. A complete Minimum Requirement for ADS-B data is discussed in [10].

This paper will discuss the signal quality in terms of Probability of Target Report (PTR) and the radiated emission of the ADS-B receivers.

IV. Results and Discussion

A. ADS-B Signal Quality in Terms of Update Interval Rate and Reception Probability

Direct interviews with 30 entrepreneurs determine decision-making attributes (criteria), decision-making criteria and values. This value can be changed in the application based on the conditions desired by the user.

Statistical data of ADS-B receiver is discussed in [6] related to signal quality. The data was collected for six months. The Results are satisfactory and similar to the results published by EUROCONTROL and FAA 86.42% of them meets the EASA requirements in RAD environment. Currently there is a large amount of ADS-B data available from several ADS-B stations in the world, which may be used for profiling the aircraft based on the kinematic characteristics to identify anomalies or unusual behavior of some aircrafts [9].

In this paper ADS-B is collected in a few hours only and then the collected data is analysed to assess their signal quality. The test setup of collecting ADS-B data has been performed in two types of test setup.

- *Test Setup 1:*

ADS-Breceiver is located on the third building of PTE-BPPT and received signals from ADSB-based surveillance transmitter which transmit ADS-B data to monitor ground vehicles (A-SMGCS) as shown in Figure 1.

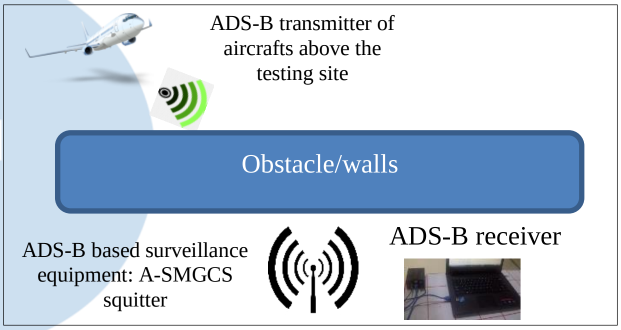


Fig. 1. First phase of test setup 1 of ADS-B signal quality testing with receiver inside the walls

At the first phase of testing, ADS-B receiver is conditioned to receive only ADS-B messages from A-SMGCS squitter for ground movement monitoring (ADS-B transmitter). The first phase of this testing has the setup as given in Figure 2.

Fig. 2. First phase of test setup 1, ADSB receiver only receives signal from A-SMGCS squitter

During this first phase of testing the antenna is blocked from the open sky to ensure no ADS-B messages received from aircrafts. The result is given in Table 2. Table 2 shows that the Probability of Reception (Probability of Target Report/PTR) is higher than the required PTR value of 95 % when there is no received data from aircrafts. The receiver received only the transmitted data from ADS-B transmitter for ground vehicles.

TABLE II. RESULTS OF FIRST PHASE OF THE TEST SETUP 1 RELATED TO UPDATE INTERVALS AND PROBABILITY OF RECEPTION

Testing Parameter	Values	Units
Average Update Intervals	0.50	Second
Duration Time of Testing	1050.26	Second
Total Transmitted Data from ADS-B transmitter for ground movement monitoring	2100	Frames
Probability of Reception	**99.595**	%
Frame Loss	0.4054242	%
Total Detected Aircraft	0	aircraft

At the second phase of testing, ADS-B receiver is receiving not only data from ADS-B transmitter for ground vehicles, but received data from overflying aircraft above PTE-BPPT building which transmit ADS-B messages. The test setup of this 2nd phase of testing 1 is shown in Figure 3 and Figure 4. The result is given in Table 3.

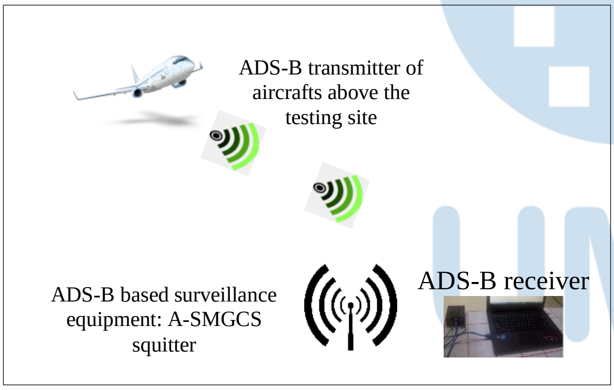


Fig. 3. Second phase of test setup 1 of ADS-B signal quality testing, ADS-B receiver has antenna open to the sky

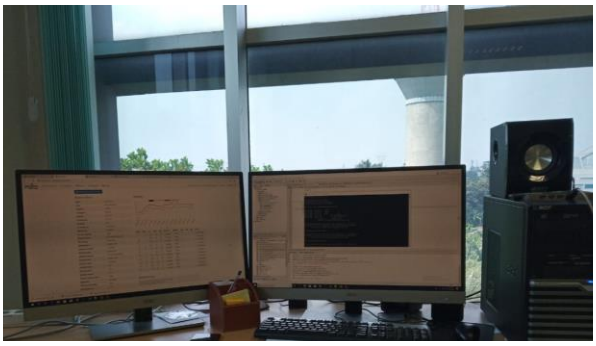


Fig. 4. Second phase of test setup 1, ADSB receiver receives signal from A-SMGCS squitter and the overflying aircrafts

TABLE III. RESULTS OF SECOND PHASE OF THE TEST SETUP 1 RELATED TO UPDATE INTERVALS AND PROBABILITY OF RECEPTION

Testing Parameter	Values	Units
Average Update Intervals	0.80	Second
Duration Time of Testing	929.98	Second
Total Transmitted Data from ADS-B transmitter for ground vehicles	1859	Frames
Probability of Reception	**62.582**	%
Frame Loss	37.418144	%
Total Detected Aircraft	23 to 26	aircraft

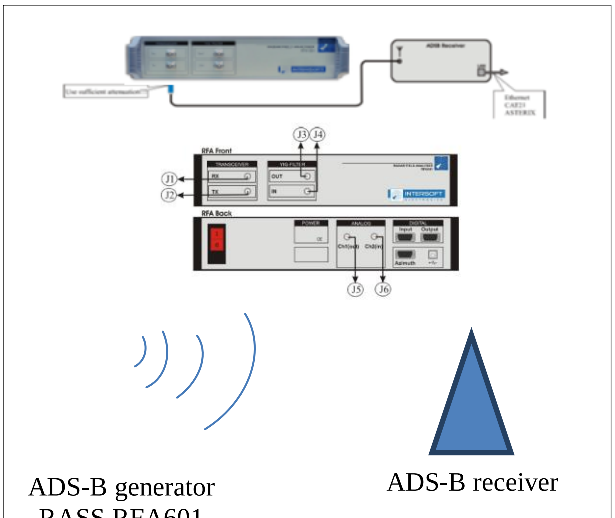
In this phase the performance of ADS-B receiver in terms of PTR has decreased to 62.582%, which is lower than the required PTR value. The ADS-B receiver received both data from ADS-B transmitter for ground vehicles and from 23 to 26 aircrafts overflying the PTE-BPPT building. The average update intervals are increasing too from 0.5 seconds to 0.8 seconds.

The decreased value of PTR may result for a possible data collisions since the ADS-B receiver used port that received only status data, Data Format (DF) 17 and DF-18 with a correct CRC bits (wrong data which is transmitted correctly will have a correct CRC bits. There is another port communication in the A-DSB receiver available which may report all datas including status data, error messages, and the DF17 and DF18 data.

- *Test Setup 2:*

ADS-B receiver is located on the second building of PTE-BPPT and received ADS-B signals generated from RASS Radar Field Analyser RFA 641 (Figure 5 and 6). RFA 641 generates a simulated ADS-B message DF18 which is received by ADS-B receiver.

In the first phase the RFA 641 generates ADS-B messages DF18and transmitted through a coaxial cable and then received by the ADS-B receiver.



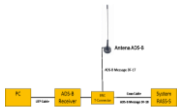


Fig. 5. Test setup 2 first phase which is the RFA 641 connected through coaxial cable to the A-DSB receiver [13]

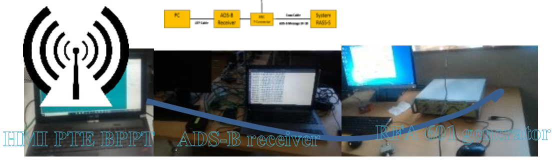


Fig. 6. Test setup 2 of ADS-B signal quality testing

The results of test setup 2 are given in table 4. The 2nd test setup has been conducted in two phases. The 1st phase by directly connecting with a coaxial cable from RASS to ADS-B receiver. The 2nd phase of this set up, the RASS is still connected to ADS-B receiver by using a coaxial cable but in addition an antenna is attach to the ADS-B receiver to received signals from the overflying aircraft. Total received messages during the first phase of 2nd test setup is 1703 messages, while the total received messages during the second phase of 2nd test setup is 18.567 messages. The number of messages received at the second phase of testing is almost 10 times more messages than number of messages at first phase. The number of surface position messages during the second phase of testing is very low (491 messages).

During the time of observation the aircraft and ASMGC-S squitter tracking is effected by the amount of data losses. The tracking object is sometimes loss of track during this observation period. This results in loss of track in the HMI (Human Machine Interface) of ADS-B receiver as shown in Figure 7.

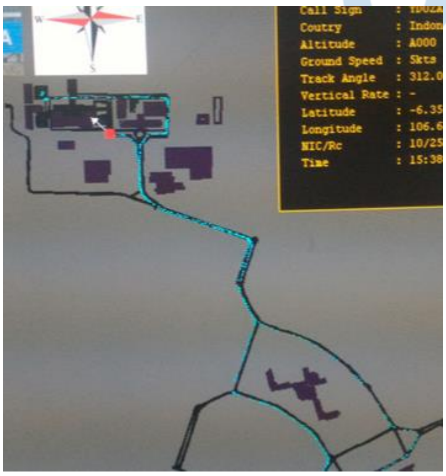


Fig. 7. Loss of track due to the data losses during the observation period of ASMGCS squitter

TABLE IV. RESULTS OF THE TEST SETUP 2 RELATED TO NUMBER OF DATA RECEIVED BY ADS-B RECEIVER

	15-08-2018	
	Coax cable from ADS-B receiver to RASS (1st phase)	**Coax cable and antenna ADS-B receiver (2nd phase)**
Starting Time	***15:22:03***	***15:46:01***
Total Airborne position message	0	7962
Total Surface position message	1619	491
Total Emergency message	0	217
Total Identification message	84	827
Total Velocity message	0	7895
Total Unknown Extended Squitter message	0	739
Total ADSBStatus message	0	436
Total Messages	***1703***	***18567***

In addition, there is a decrease in performance related to update interval. Average update interval during the first phase of 2nd test setup is 554 msec, while in the 2nd phase the average update interval decreases to 1829 msec as shown in Table 5.

TABLE V. RESULTS OF THE TEST SETUP 2 RELATED TO UPDATE INTERVAL TIMES

Test Setup 2 and the connection between RASS and ADS-B receiver:	**Update Interval (milli seconds)**			**Total Observation Time**
	min	**avg**	**max**	**(seconds)**
Coax cable (1st phase)	201	554	2103	896
Coax cable and additional antenna (2nd phase)	301	1829	9859	889

The decreased value of PTR may cause by a possible data collisions since the ADS-B receiver used port that received only status data, Data Format (DF) 17 and DF-18 with a correct CRC bits (wrong data which is transmitted correctly will have a correct CRC bits. There is another port communication in the A-DSB receiver available which may report all datas including status data, error messages, and the DF17 and DF18 data.

In addition, the horizontal offset is calculated as in equation 1 by using a refence position near PTE

BPPT's building. The difference of horizontal offset between phase 1 and phase 2 in 2nd test setup is equal to 205 meter in average, with its minimum is equal to 152 meter and its maximum is equal to 1466 meter.

B. ADS-B Receiver Radiated Emission

In [12] a study about dropout rate of ADS-B messages from ADS-B receivers has shown that different type of aircrafts may have different duration of dropout time. The type of ADS-B transmitters and receivers used to receive ADS-B data has a significant impact into the duration of dropout time. The dropout rates are the number of times the data did not indicate a one second update period. The dropout rates are categorized into several data starting from the number of dropout of is less than 10seconds (over 49% of dropouts are in this category) until the number of dropout is greater than 60 seconds (about 7% of dropouts are in this category).

In the 2nd test setup with a coaxial cable connection only between RASS and ADS-B receiver, the number of received signal with dropout time less than 10 seconds is 92.89 %, while the number of received signal with dropout time between 10 seconds and 60 seconds is 7.10 %. There is no dropout time bigger than 60 seconds.

In the 2nd test setup with a coaxial cable connection and an additional antenna attach to ADS-B receiver, the number of received signal with dropout time less than 10 seconds is 98.52 %, while the number of received signal with dropout time between 10 seconds and 60 seconds is 1.78 %. There is 0.05% dropout time bigger than 60 second.

TABLE VI. RESULTS OF THE TEST SETUP 2 RELATED TO NUMBER OF DROPOUT DATA

Dropout Time	Coax Cable (1st Phase)	Coax Cable+Additional Antenna (2nd Phase)
less than 10 seconds	0.9289	0.9852
between 10 to 60 seconds	0.0710	0.0178
greater than 60 seconds	0	0.0005

The number of data generated in the duration of approximately 900 seconds, on the first phase of 2nd testing, is around 1721 data. While on the second phase of 2nd testing is around 18000 data. The number of data in the 2nd phase of testing is much higher than the generated RASS data because the ADS-B receiver is connected through a port that received not only DF17 and DF18 datas, but also additional status data of aircraft, velocity and error data too.

In order to have a better overview about the number of data received in the airport area, a measurement is conducted near Jakarta airport. The number of data received is 2950 data for both DF17 and DF18 data (see Fig.8).

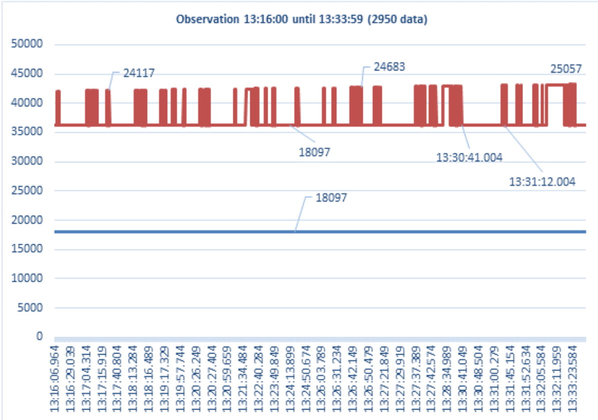


Fig. 8. ADS-B surveillance based signal strength scanning in the surrounding of Jakarta airport (dBuV)

The signal strength is approximately 25 dBuV as shown in figure 4, and the longest update interval is about 30 seconds (between 13:30:41.004 to 13:31:12.004) and some update intervals overlap. There are many signal sources from various targets, therefore testing of potential EMI (Electromagnetic Interference) from the surrounding equipment are necessary. Especially as mentioned in [11] there are many types of interference and classified into intentional interference (jamming, spoofing, and eavesdropping) and unintentional interference (EM emissions and harmonics).

EMI testing has been conducted regarding the radiated emission for both low frequency (30MHz to 1 GHz) and high frequency (1GHz to 6 GHz) (see fig.9). There are two ADS-B based receiver tested, ADS-B receiver 1 and ADSB-receiver 2.

Fig. 9. EMI testing setup fot ADS-B testing

Table 7 shows the result of EMI testing for high frequency radiated emission for the first ADS-B based receiver, while table 8 shows the result for the second ADS-B receiver.

TABLE VII. RESULTS OF RADIATED EMISSION HIGH FREQUENCY OF ADS-B RECEIVER 1

Freq	PKk	Limit PK	AVG	Limit AVG	Margin PK	Margin AVG
MHz	dBuV	dBuV	dBuV	dBuV	dBuV	dBuV
1821.249	46.504	70	43.303	50	-23.496	-6.697

TABLE VIII. RESULTS OF RADIATED EMISSION HIGH FREQUENCY OF ADS-B RECEIVER 2

Frequency	PK	Limit PK	AVG	Limit AVG	Margin PK	Margin AVG
MHz	dBuV	dBuV	dBuV	dBuV	dBuV	dBuV
1819	45.318	70	41.519	50	-24.682	-8.481

The above figures show that the radiated emission at high frequency (1 GHz- 6GHz) is stronger in some frequency generated by the first ADS-B receiver, namely in the frequency of 1821.240MHz which has a value of 43.303 dBuV. Other frequencies have almost similar strength.

Table 9 shows the result for radiated emission in low frequency of ADS-B receiver 1 and Table 10 shows the result for radiated emission in high frequency of ADS-B receiver 2.

TABLE IX. RESULTS OF RADIATED EMISSION LOW FREQUENCY OF ADS-B RECEIVER 1

Frequency	PK	QP	Lmt_QP	Margin
MHz	dBuV	dBuV	dBuV	dB
31.08	-3.941	-8.793	40	-48.79
960.012	24.517	21.921	47	-25.08

TABLE X. RESULTS OF RADIATED EMISSION LOW FREQUENCY OF ADS-B RECEIVER 2

Frequency	PK	QP	Lmt_QP	Margin
MHz	dBuV	dBuV	dBuV	dB
32.004	-4.3	-9.264	40	-49.26
912	30.144	28.704	47	-18.3
959.986	26.893	24.785	47	-22.21

The above figures show that the radiated emission at low frequency (30 MHz- 1GHz) is stronger in some frequency generated by the second ADS-B receiver, namely in the frequency of 959.986 MHz which has a value of 24.785 dBuV. In addition, there is additional emission in the frequency 912MHz with a value of 28.704 dBuV. These frequencies will not have potential interference with ADS-B signal.

In addition, a measurement is conducted in the surrounding area of ADS-B receivers to collect information regarding potential electromagnetic interference in the ADS-B and GNSS frequency range. The result is given in Figure 10.

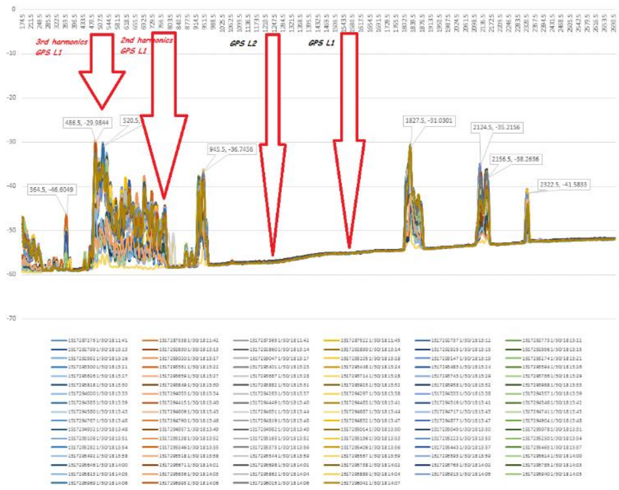


Fig. 10. Potential electromagnetic interference to the GNSS receiver inside ADSB [15]

The above figures show that there is a potential Electromagnetic Interference to the GNSS receiver in ADS-B [15].

V. CONCLUSION

This paper presented testing data analysis from various test setups to acquire update interval times, probability of reception, dropout data interval, and the radiated emission of two ADS-B receivers. If the data is generated from RFA 601, then the update interval is approximately 0.5second and the probability of reception is approximately 99.595% which is above the requirement of EUROCAE. When the data is received from both RFA 601 and an attached antenna, the update interval is approximately 0.8 second and the probability of reception has decreased into 62.582%, which is below the requirement of EUROCAE. A further study is necessary to assess whether lower probability of reception is caused by the option of port connection which transmit all data including error messages by trying different ports of connection in a longer observation time. Most of dropout time is less than 10 seconds and there is no dropout time is bigger than 60 seconds. A further statistical data analysis of ADS-B based surveillance equipment is necessary to assess the performance of this equipment in both signal quality and radio frequency interference. In addition, the radiated emission test results show that two ADS-B based surveillance equipment have similar radio frequency emission but with different field strength. A further study is necessary to assess more ADS-B based surveillance equipment in order to have a better data analysis.

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References

[1] Verbraak, T. L., Ellerbroek, J., Sun, J., & Hoekstra, J. (2017). Large-Scale ADS-B Data and Signal QualityAnalysis. In 12th Seminar Papers: 12th USA/Europe Air Traffic Management Research and Development Seminar.

[2] R. Michael Guterres1, Stanley R. Jones2, Gregory L. Orrell3, Robert C. Strain4, ADS-B Surveillance System Performance with Small UAS at Low Altitudes, American Institute of Aeronautics and Astronautics, 2017 The MITRE Corporation.

[3] Taehwan Cho, Changho Lee and Sangbang Choi, Multi-Sensor Fusion with Interacting Multiple Model Filter for Improved Aircraft Position Accuracy, Sensors 2013, 13, 4122-4137; doi:10.3390/s130404122.

[4] Edan Habler Asaf Shabtai, Using LSTM Encoder-Decoder Algorithm for Detecting Anomalous ADS-B Messages.

[5] Mr Leon Purton, Professor Hussein Abbass and Dr Sameer Alam, Identification of ADS-B System Vulnerabilities and Threats, Australasian Transport Research Forum 2010 Proceedings, 29 September – 1 October 2010, Canberra, Australia, Publication website: http://www.patrec.org/atrf.aspx.

[6] EUROCAE, 2005: Safety, performance and interoperability requirements document for ADS-B/NRA application, available at: http://adsb.tc.faa.gov/RFG/ADS-B-NRA%20SPR-INTEROP%20_ED-126_%20v1.0.pdf.

[7] Simon Tesi1, Stanislav Pleninger1*, Analysis of Quality Indicators in ADS-B Messages Magazine of Aviation Development, 5(3):6-12, 2017, ISSN: 1805-7578 DOI: 10.14311/MAD.2017.03.01.

[8] Ryan Salcido, Anthony Kendall, Ying Zhao, Analysis of Automatic Dependent Surveillance-Broadcast Data, Deep Models and Artificial Intelligence for Military Applications: AAAI Technical Report FS-17-03, 2017, Association for the Advancement of Artificial Intelligence (www.aaai.org). All rights reserved.

[9] FabriceKunzi, ADS---B BENEFITS TO GENERAL AVIATION AND BARRIERS TO IMPLEMENTATION, Master of Science in Aeronautics and Astronautics Thesis, 2011 Massachusetts Institute of Technology.

[10] William Semke et al., Analysis of Radar and ADS-B Influences on AircraftDetect and Avoid (DAA) Systems, Aerospace 2017, 4, 49; doi:10.3390/aerospace4030049.

[11] Brandon Kovell, Comparative Analysis of ADS-B Verification Techniques, paper submitted as partial fulfillment of the requirements for the degree of Masters in Interdisciplinary Telecommunications at the University of Colorado, Boulder, 4 May 2012.

[12] Asma Tabassum * and William Semke, UAT ADS-B Data Anomalies and the Effect of Flight Parameters on Dropout Occurrences, Data 2018, 3, 19; doi:10.3390/data3020019.

[13] Radar Field Analyser - RFA641User Manual, IE-UM-00165-003 RFA641 User Manual.odt, Edition: 003 Date: 11-Dec-12.

[14] Nicholas Allen, Evan Arnold, Dr. J.W. Bruce, Matthew McCrink, Mohammad Moallemi, Dr. William Semke, Kyle Snyder, Dawson Stott, Asma Tabassum, Dr. Michael Wing, UAS Surveillance Criticality Final Report, actlibrary.tc.faa.gov December 2016.

[15] Reza Septiawan et.al. GNSS interference reduction method for CORS site planning, telkomnika journal of telekomunikasi 2018.

[16] EUROCAE ED-87, Minimum Aviation System Performance Specification For Advanced Surface Movement Guidance And Control Systems (A-SMGCS) Levels 1 and 2, 2015.