Classification Electromagnetic Interference Impact of VOR, ILS, and GBAS Radio Navigation Systems Operating in the VHF Band

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The active use of radio systems in the VHF spectrum and the overloading of this spectrum have made the presence of electromagnetic interference noticeable especially for systems in which proper operation is critically important. Radio systems equipment intended for aeronautical service groups is undoubtedly one of them (VOR, ILS, GBAS). Today, specialists' main challenge is reducing these interferences, several recommendations have been issued both by ICAO and ITU. In this study, we investigate possible causes of these errors Such as intermodulation, wireless attack, and anomalous wave propagation.

In all three regions of the radio regulation voice, radio broadcasting is VHF-band until 78.5-108 MHz and for air navigation services specifically for instrument landing systems ILS and also for GBAS are assigned 108-112 MHz these systems are under the threat to become vulnerable from superior emissions which requires prevention to reduce the interference to the minimum.

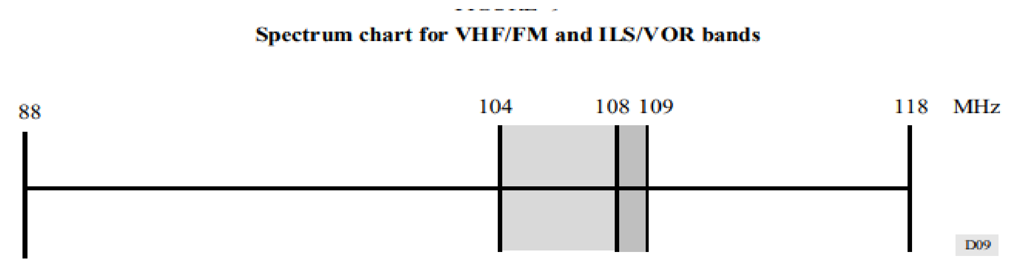

Figure 1 This photo shows the range where interference is most common in VHF spectrum

The main types of interference:

Aircraft's antennas are vulnerable to electromagnetic interference. These interferences themselves are not of one kind, but mainly interference occurs in two cases first, when the operating frequency radio bands of two systems are too close to each other that the transmitter of one system produces unwanted emissions to the other system's receiver in its broadcast frequency bands. Or, when the operating frequencies of the two systems are quite far apart but high-frequency harmonics in the transmitter spectrum may affect the other frequency band for the receiver. Also, additional electromagnetic interference can be generated from the aircraft systems themselves due to their high-performance speed. In more detail, the types of electromagnetic interference are classified as type A and type B interference.[4] These categories are classified but in practice on radio navigation systems this case is much more complicated and in many cases, it is difficult to define specific types of interference, since one particular receiver may be vulnerable to both type A and type B interference. Our research deals with this phenomenon and examines the reasons which are: anomalous propagation, intermodulation harmonics generated from radio broadcasting transmitters or systems working on adjacent frequencies.

Above mentioned unwanted emissions type A1 interference is when one or several broadcasting transmitters can create superiors emission for the aeronautical frequency band or when they can produce intermodulation components in the aeronautical band. [4] Type A2 interference happens when interference is coming from only from the broadcasting transmitters whose working frequencies are near 108 MHz and in practice has effect only on ILS localizer and VOR service. [1] Type B interference is when interference is coming from the aeronautical receivers resulting from the broadcasting transmitter of which frequencies are out of the aeronautical band. [4] Type B1 interference Intermodulation may be generated in an aeronautical receiver as a result of the receiver being driven into non-linearity by broadcasting signals outside the aeronautical band

For this type of interference to occur, at least two broadcasting signals need to be present and they must have a frequency relationship that, in a non-linear process, can produce an intermodulation product within the wanted RF channel in use by the aeronautical receiver. One of the broadcasting signals must be of sufficient amplitude to drive the receiver into regions of non-linearity but interference may then be produced even though the other signal(s) may be of significantly lower amplitude.[4]

We will carry out this research using the CAM (Common Assessment Method) CAM is a proven method for calculating all possible incompatibilities on the aeronautical systems at multiple points. This method has already been used in many similar studies, [11,[3]

Wireless attack

We consider interference attack two types, overshadow attack where the attack transmits specially crafted powerful signals level where the reference signal will be overpowered at the receiver the main reason why this attack work is the receiver is locked and the strongest signal is processed by the receiver. Figure 2 shows how is this process in the CDI

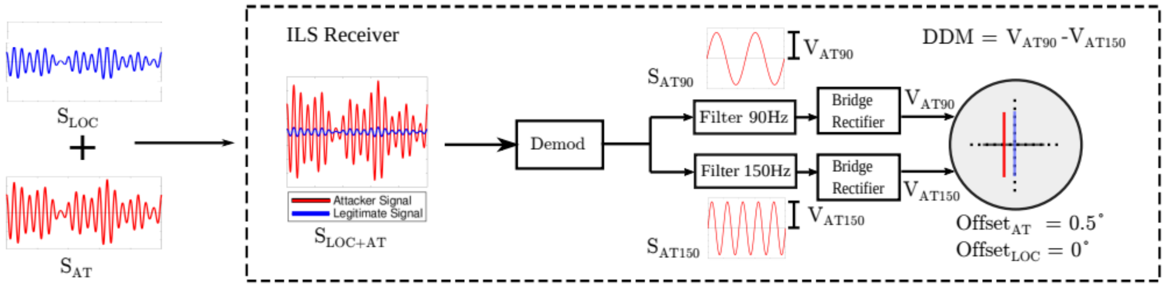

Figure 2. This photo shows how an attacker sends a false signal and how the CDI reacts

Second type is signal tone attack, where there the attack transmits only one of the sideband tones (90Hz or 150HZ) to create deflection on the CDI it does not require high-power spoofing signals. **Spoofing is Cyber-weapon attack that generates false signals to replace valid ones.**

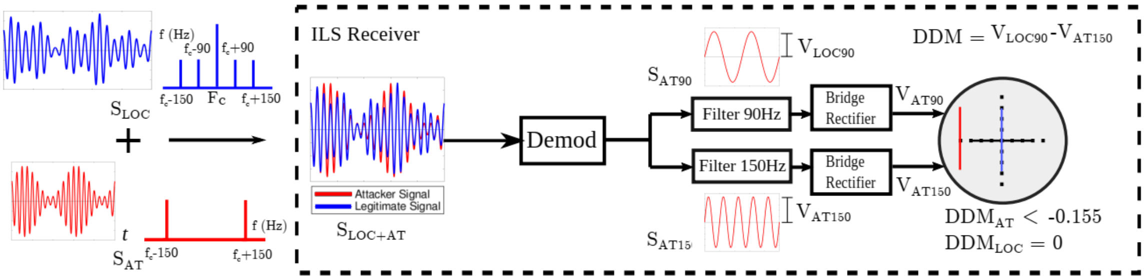

Figure 3: Schematic of the single-tone attack. Attacker constructs a DSB-SC signal without the 90 Hz component and the carrier. The blue line represents the needle position without the attack

Both methods were very dangerous. This study was conducted in a simulated environment and both attacks resulted in the aircraft missing the landing point due to the wireless interference attack. In overshadow attack the aircraft landed 18 meters away from the center line and 800 m beyond the safe touch-down zone as figure 4 shows and it is very dangerous because such a small deviation from the runway may not be detected by ATC. But the single-tone attack will more dangerous because of the power required to case CDI deflection as the attacker only transmits one of the sideband components without the carrier. [3]

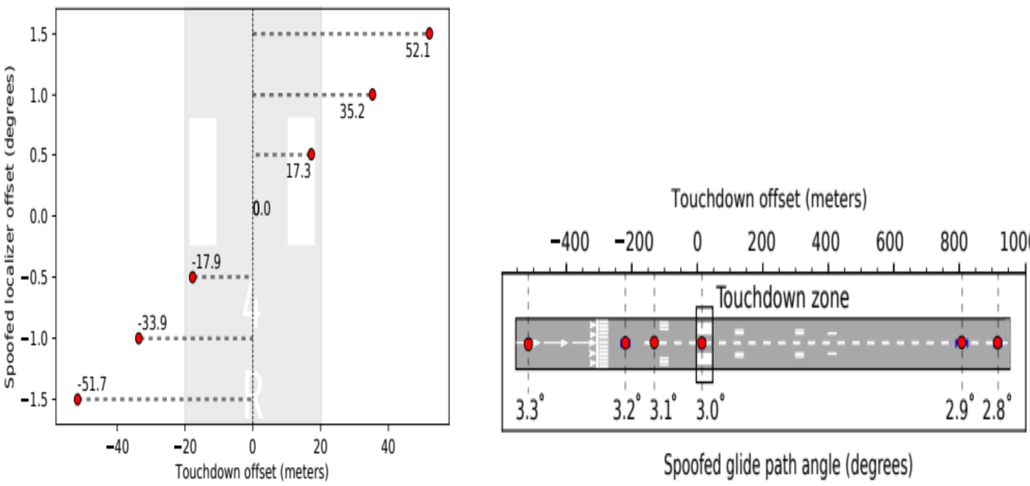

Figure 4. This photo shows the touch-down points obtained by the error resulting from the attack

Anomalous propagation VHF wave

Sporadic E propagation in the ionosphere, makes it likely that additional disruptions will occur. [ ] These processes\ are taking place mainly at the E level of the ionosphere It has been known for a long time E layer can cause anomalous propagation for VHF frequency waves that normally can pass through the ionosphere. But during certain anomalies, it is possible to reflect the VHF waves from ionosphere, which can cause anomalous propagation and it has a negative effect on aeronautical infrastructure should be noted that this phenomenon can cause both type A and type B interferences for ILS, GBAS, and VOR Because the wave that is reflected in specific layers of the ionosphere can be from a radio broadcasting transmitter or from any aeronautical infrastructure. And this reflected wave can spread thousands of kilometers and affect the radio navigation systems located at the airport. Figure 5 is a schematic diagram showing such anomalous propagation in the case of VOR signals. [2][6]
Due to the VHF wave properties, they are so-called Line of Sight waves(LOS) Since they are not reflected in the ionosphere, the operating distance of these waves is approximately 200 nm from the radio transmitter. However, when Es appears and the electron density at around 100 km is high enough to reflect VHF radio signals with larger incident angles, the waves can propagate beyond a certain distance It is known that such anomalous propagation occurs in a distance of 600–2500 km from the radio transmitter, which has a potential to cause interference with normal propagation signals (Sakai et al. 2019). And distances between 200 and 600 km from the source are skip zone (Davies 1969) . Continuous observations of anomalous long-range propagation of VHF radio waves due to Es allow us to evaluate the impact of Es on the aeronautical NAV systems. And also it is possible to map the 2D spatial distribution of Es, which can affect the NAV systems.[6]

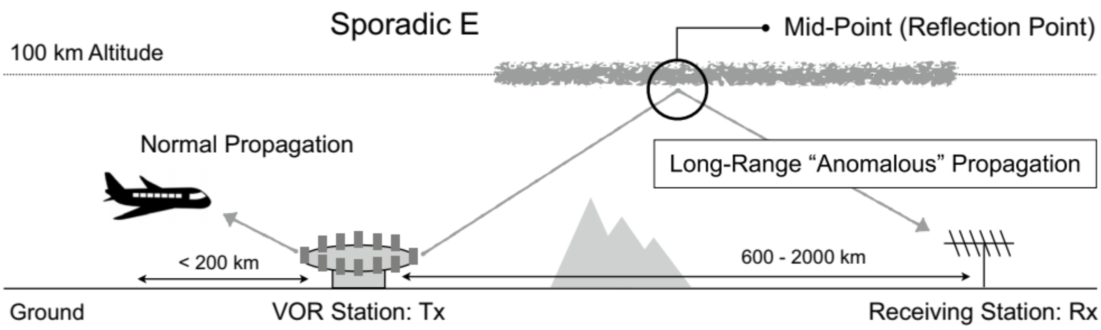

Figure 5 is a schematic diagram showing such anomalous propagation in the case of VOR signals

Intermodulation

Unwanted interference affects all systems that are placed on the aircraft, but the most vulnerable to interference are navigation systems, especially those systems that operate in the VHF range, such as ILS 108.1 - 111.95 MHz System Localizer VOR 108.00 - 117.975 Mhz and GBAS 108 to 117.975 MHz. It is also important to interfere with radio communication systems that are also located in the VHF frequency spectrum and are the main communication between them and dispatch services. Therefore, in the area of any airport and near it, it is necessary to study the sources of interference, because superior emission on these systems may cause incorrect measurement and system failure.[11][9]

Operating in the non-linear region can create distortion in the form of harmonics and intermodulation products usually amplitude of a harmonic decrease as the harmonic order increases Intermodulation is the same but it occurs when two or more signal mix in the non-linear device, the mixing produces new signals at the sum and difference of their two frequencies [11]

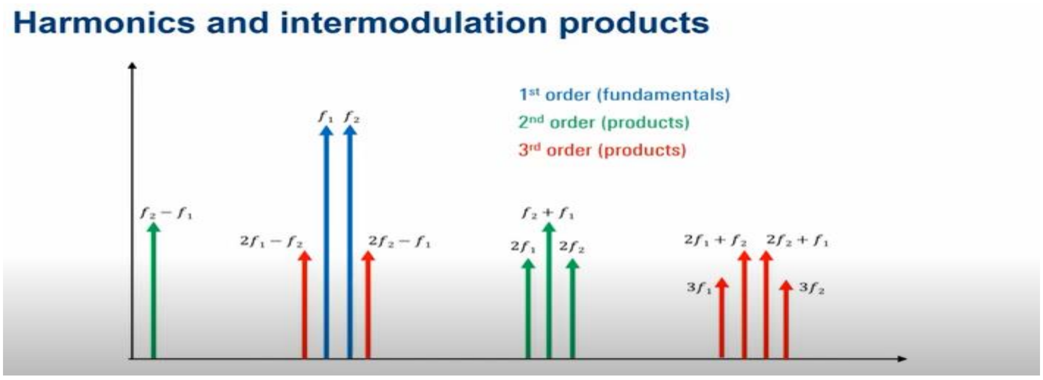

Figure 6 the form of harmonics and intermodulation products

Harmonics and intermodulation always are undesired signals that can produce leakage into adjacent channels, noise, and distortion undesired intermodulation is often referred to as intermodulation distortion (IMD) Interference can also be caused by corroded cables and other metal objects located near receivers and transmitters. Some problems are easy to deal with, for example: higher order harmonics have very low amplitudes and usually be ignored also higher frequency products often fall outside of amplifier bandwidth, filter passbands and etc. Filtering is effective to avoid this problem but it is difficult when the products are very close in frequency to the desired (fundamental) signals in this picture No 2f1-f2 and 2f2-f1 is a problem and near the fundamental signals. Besides the filtering issue, third-order intermodulation products present an additional complication. For every 1 dB increase in the fundamental signals the third order intermodulation products increase level by 3 dB so it would appear these two lines on the picture would meet at some point but in reality output power no longer increases linearly with the input power and gain lines begin to curve or flatten out as the device use into compression. [11] [10]

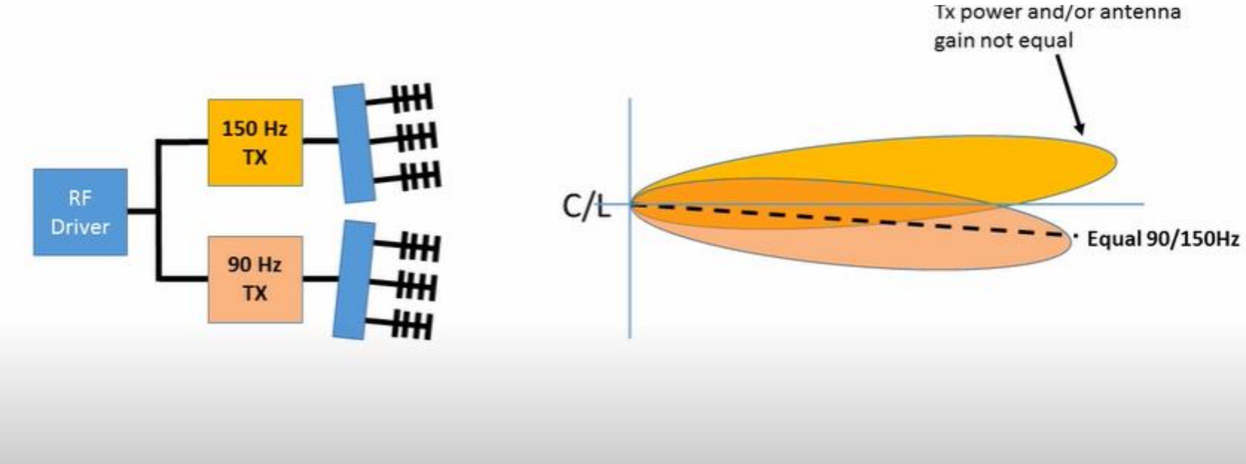

Figure 7 when localizer Tx power and /or antenna gain not equal

That is why intensive radio monitoring is crucially important. The corresponding frequency band is particularly vulnerable in the range of 104-109 MHz because this represents marginal frequencies where the frequency band starts for aeronautical services and ends the frequency band for civil radio sound broadcasting and those systems that use these frequencies especially need observations and studies.

Having these systems together increases the chance of interference, and these systems can interfere with each other. In fact, in the ICAO and FAA recommendation, it is written that in America and Europe there are interferences from the localizer and VOR to the GBAS system, this problem is naturally due to the following things Since we know that the localizer, VOR, and GBAS systems, all three systems are placed in the VHF frequency spectrum where problems mentioned above are at work.[5][7]

Conclusion

Today, when the VHF spectrum is very overflowing and most of the radio navigation systems are in this spectrum, the risks of interference are really high. That is why we should think about minimizing the risks of this interference. This very important issue is discussed in the paper above. In addition to the overloading of the spectrum, interferences may originate from certain layers of the ionosphere, so it is desirable to create observation stations. If we have information that there is a composition in the ionosphere at a particular location that is likely to cause anomalous propagation that will have an effect on radio navigation systems hundreds and thousands of kilometers away from that location, the problem will be solved if the information is available. It is also necessary to study the sources of interference in the airport area in order to minimize superior emissions to radio navigation systems.

References:

[1] Aviation, International Civil. 2018. manual of testing radio navigational aids. Montréal: INTERNATIONAL CIVIL AVIATION ORGANIZATION, 166.

[2] H. Shinagawa, T. Tsugawa,. 2013. Two-dimensional simulation of ionospheric variations in the vicinity of the epicenter of the Tohoku-oki earthquake. technical report, Tokyo: SpringerOpen, 10.

[3] Harshad Sathaye, Domien Schepers, Aanjhan Ranganathan, and Guevara Noubir. 2019. „Wireless Attacks on Aircraft Instrument System (ILS)." USENIX 17.

[4] ITU, radiocomunication sector of ITU. 1995. Compatibility between the sound-broadcasting service inthe band of about 87-108 MHz and the aeronautical services in the band 108-137 Mhz. recomendation, Geneva: Rec. ITU-R SM.1009-1, 41.

[5] J.Ely, Jay. 2005. Electromagnetic Interference to Flight Navigation and comunication systems new strategies in the age of wireless. book, Hampton: NASA Langley Research Cente, 29.

[6] Keisuke Hosokawa1* Jun Sakai1. 2020. A monitoring network for anomalous propagation of aeronautical VHF radio waves due to sporadic E in Japan. online source .

[7] Larsen, Clifton A. Clarke William E. 1987. aircraft electromagnetic comapatibility. Springfield, VA 221 61 .

[8] Moore, Roberto sabatini Subramanian Ramasamy Terry. 2017. „Global Navigation Satellite Systems Performance Analysis and Augmentation strategies in aviation." Elsevier (Elsevier) 52.

[9] R&S. n.d. "aeronautical radio navigational measurment solution." 42.

[10] Rohde&Schwarz, R&S f. 2019. Verify your GBAS signal with high performance. Munich: f Rohde&Schwarz, 2.

[11] T B Iliev, I S Stoyanov, G Y Mihaylov and E P Ivanova. 2021. „Study the influence of intermodulation products on navigation." IOP Conference Series. Bristol: IOP Publishing. 10.

VHF დიაპაზონში მომუშავე რადიო სანავიგაციო სისტემებზე VOR, ILS, GBAS ელექტრომაგნიტური ჩარევების კლასიფიკაცია

რამინ კუჭუხიძე
თეიმურაზ ქორთუა
საქართველოს საავიაციო უნივერსიტეტი ქეთევან დედოფლის გამზ. 16-0103 თბილისი, საქართველო

დღეს, როდესაც VHF სიხშირეთა სპექტრი ძალიან გადატვირთულია და რადიო სანავიგაციო სისტემების უმეტესობა ამ სპექტრშია ჩართული, ელექტრომაგნიტური ხელშეშლების რისკი ძალიან მაღალია, სწორედ ამიტომ უნდა ვიფიქროთ ამ ხელშეშლების მინიმუმამდე შემცირებაზე. ამ ნაშრომში განხილულია ეს მნიშვნელოვანი საკითხები. სპექტრის გადატვირთვის გარდა ელექტრომაგნიტური ინტერფერენცია შეიძლება გამოწვეული იყოს იონოსფეროს გარკვეული შრეებიდან, სწორედ ამიტომ სასურველია შესაბამისი სადამკვირვებლო სადგურების შექმნა, რადგან თუ ჩვენ დროულად გვექნება ინფორმაცია, რომ იონოსფეროში კონკრეტულ ადგილას არის ხელსაყრელი შემადგენლობა ტალღის ანომალური გავრცელებისთვის, რასაც გავლენა ექნება რადიო სანავიგაციო სისტემებზე, ასობით და ათასობით კილომეტრის დაშორებით, პრობლემა მოგვარებადია.