

HIRF Tolerance and Avoidance for Advanced Air Mobility Vehicles

Truong X. Nguyen

NASA Langley Research Center, Hampton, VA, USA, email: truong.x.nguyen@nasa.gov

Abstract— Advanced Air Mobility (AAM), including Urban Air Mobility (UAM), and Unmanned Aerial Systems (UAS) vehicles may fly in similar airspace to Transport Category Rotorcraft, thereby requiring meeting the same stringent High-Intensity Radiated Fields (HIRF) certification requirements. In a previous effort, a proposed map-based approach protects a vehicle by keeping it away from high power sources at safe distances based on its tolerance level. By designing to a lower tolerance level, significant cost savings can be achieved at the cost of slightly more complex flight planning. However, too low a threshold can result in large avoidance areas, potentially reducing the vehicle operating space. This current effort suggests a minimum threshold for vehicles operating in an urban area. It is derived from analyzing regulatory transmitter data for New York City as a representative metropolitan area. As a result, a vehicle can tolerate common lower-power transmitters by default and only needs to avoid far less common high-power sources. It is also found the existing HIRF requirements may be insufficient against many powerful transmitters such as weather radars and satellite uplink transmitters, and that the map-based approach can address this concern.

Keywords—HIRF, Map, AAM, UAM, UAS, Advanced Air Mobility, Urban Air Mobile, Unmanned Aerial Systems, Certification

I. INTRODUCTION

Airborne vehicles can suffer from electromagnetic interference or damage due to high-intensity radiated fields (HIRF) sources such as radars, terrestrial and satellite uplink transmitters, TV towers, microwave links, etc. Rotorcraft HIRF certification environment [1-3] is severe because they operate closer to the ground and can be directly illuminated by powerful ground transmitters. HIRF protection against severe environments could increase vehicle cost, size, and weight.

Advanced Air Mobility (AAM) vehicles, including Urban Air Mobility (UAM), and Unmanned Aircraft Systems (UAS), may be required to meet the same stringent HIRF requirements as rotorcraft as many vehicles can operate close to the ground and hover in front of powerful transmitters. UAM refers to using aerial vehicles, including drones and air taxis, to transport passengers and cargo within an urban area [4]. AAM is an extension of UAM that encompasses a broader range of aerial vehicles and transportation services beyond urban areas. UAM and AAM envision a future where air transportation significantly enhances connectivity and accessibility across different environments. Reducing the HIRF protection costs while maintaining a similar level of safety is of significant interest for these newer vehicles. Ref. [5] offers an assessment

of the suitability of the standard aircraft environment for UAM vehicles.

The previous effort [6] detailed a novel map-based approach that potentially lower the HIRF protection cost. Termed HIRF-Map, the approach keeps a vehicle at safe distances away from fixed ground transmitters and allows for an arbitrarily lower tolerance threshold than the standard requires. The concept is illustrated in Fig. 1 where HIRF zones are highlighted in red for avoidance. A vehicle flight path is intentionally charted to avoid those zones to reduce interference risks (blue dashed line).

In the standard approach, the environment was developed starting with a survey of the most powerful transmitters in the US and Europe. A set distance from the transmitter determines the vehicle tolerance requirements. In contrast, this map-based approach allows for arbitrary vehicle tolerance specified by the developer, and the vehicle needs to stay at a safe distance from the transmitters. This approach can allow lower tolerance than the standard, but the individual transmitter's location and power must be known.

This paper extends the earlier effort [6] by recommending a minimum vehicle HIRF threshold. This threshold protects against the numerous common and low-power transmitters while minimizing the avoidance zones from high-power transmitters to acceptable sizes. A lower threshold is desirable and can help lower vehicle cost and weight, but too low a threshold results in large avoidance zones that could take up too much space in an urban area. The recommended threshold is determined by analyzing transmitter databases for New York City as a representative urban area though more urban areas could be added in the future.

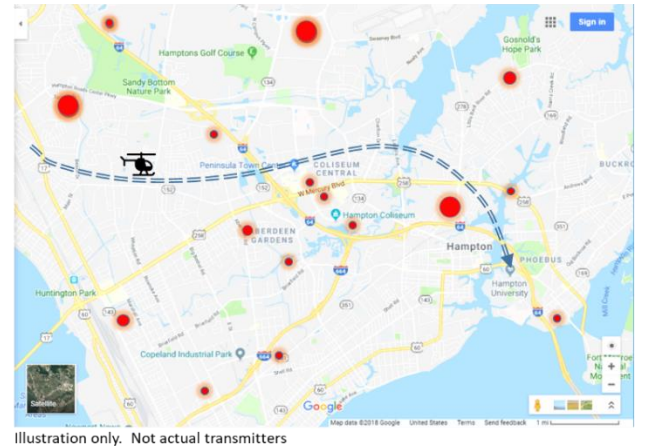


Fig. 1. Illustration of flights avoiding HIRF transmitters.

II. METHOD

The map-based approach and the transmitter databases are described in [6] and are briefly summarized in subsections A and B. Subsection C describes the approach to derive the threshold recommendation.

A. HIRF-Map Approach

The key point to this approach is that a vehicle should stay away from a transmitter sufficiently so that its field strength falls below the vehicle tolerance level. Let E_T (V/m) be the vehicle tolerance level. P_T is the HIRF transmitter's effective isotropic radiated power (EIRP), in watts. Setting the vehicle tolerance's equivalent power density, computed from E_T , to be greater than the power density from the HIRF source at distance R (in meters), then solve for R ,

$$E_T^2/377 > P_T/(4\pi R^2) \quad ,$$

$$R > (30 * P_T)^{1/2} / E_T \quad (1)$$

R is the minimum stand-off distance from the transmitter. A map is developed to highlight the region inside the radius R . High-order effects, such as reflection and diffraction, are disregarded for now for simplicity. Cumulative effects from having multiple nearby transmitters are also not considered.

It is noted that the current rotorcraft HIRF standard assumes a 100' minimum separation distance from transmitters for vehicles outside of airport environments ($R > 100m$) [1]. The field level at this distance is named '100-foot field strength' in this paper.

Matlab^T [7] Web Map are used for data processing and map display for the remainder of this paper. Examples of HIRF maps are shown in Figs. 2a and 2b where vehicle-specific HIRF zones are marked for avoidance. Fig. 2a highlights HIRF zones due to satellite uplink transmitters near Denver, Colorado for a vehicle having a 50 V/m tolerance level. This low tolerance level was chosen to enlarge the avoidance areas for better details (the recommended tolerance in a later section is 10 times higher, or 500 V/m). Antenna steering angle details are incorporated resulting in fan-shaped avoidance zones. If steering angle data are not provided in the databases, the avoidance zones become circular as they represent the worst case. Darker color shades highlight overlapping HIRF zones.

Fig. 2b shows examples of avoidance zones for microwave links, land-mobile radio, and paging transmitters. The field tolerance is only 5 V/m and is chosen to enlarge the avoidance areas for better details. The microwave beams, their direction, and stand-off distances are illustrated as narrow blue pencil beams. Land-mobile radio and paging transmitters avoidance zones are shown in green and black, respectively, with darker shades representing overlapping HIRF zones. The figure inset shows the satellite view for comparison, and that the map location data correlates very well with the actual transmitter locations.

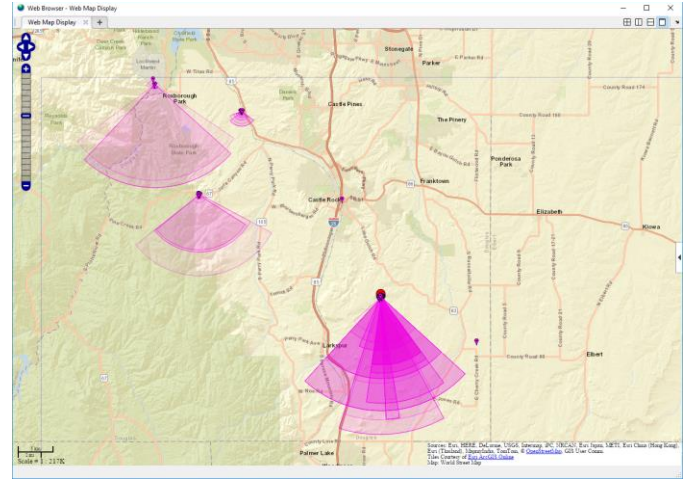


Fig. 2a: Examples of HIRF avoidance zones from IBFS transmitters. Vehicle tolerance level = 50V/m.

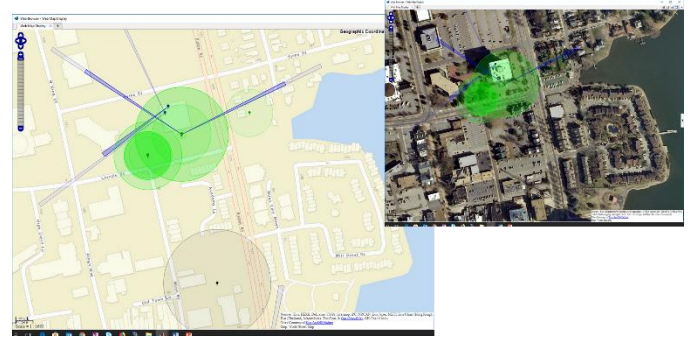


Fig. 2b: Examples of HIRF zones from ULS sources. Fixed microwave beams are shown in blue narrow beams. Land mobile radios are in green, and paging transmitters are in black.

B. Transmitter Databases

The transmitter databases considered are from the Federal Communications Commission (FCC) [8], and the National Oceanic and Atmospheric Administration (NOAA) [9] in the United States. The FCC transmitter databases contain details about licensed radio frequency transmitters, including their location, frequency bands, power levels, and other technical parameters. They serve various purposes, such as regulatory compliance, spectrum management, and coordination of radio communication activities. The FCC's HIRF-relevant databases are grouped into three systems:

- The Universal Licensing System (ULS) contains consolidated databases for many low-power services. Services relevant to HIRF include Land Mobile Radio (Broadcast Auxiliary, Commercial, and Private), Maritime Coastal & Aviation Ground, Microwave, Paging, Broadband Radio Service (BRS) & Education Broadband Service (EBS), Market-Based Services, and Cellular.
- The Consolidated Database System (CDBS) contains data for AM, FM, and TV transmitters. This system has transitioned to the Licensing and Management System (LMS).
- The International Bureau Filing System (IBFS) contains data on satellite earth-station transmitters as HIRF sources.

The IBFS has transitioned to the International Communications Filing System (ICFS).

For the New York City area, the FCC databases show transmitter EIRPs can reach as high as 75 kilowatts for ULS, 8.2 megawatts for CDBS, and 1.26 gigawatts for IBFS. Up to 75 kilowatts maximum for ULS is considered low-power in this paper. More details are in the next section.

NOAA's weather radar transmitters include the Next-Generation Weather Radar (NEXRAD) and Terminal Doppler Weather Radar (TDWR) [9]. Their maximum powers are a 700 kW peak with a 45.5 dB antenna gain and a 250 kW peak with a 50 dB antenna gain. The results are about 25 billion watts peak EIRP for both systems. The antenna power outputs may be a little less due to system losses. The worst-case average EIRP is 46.1 megawatts.

Conservative assumptions are made in calculating HIRF avoidance zones. The worst-case antenna direction, gain, and power data are used. If antenna angular data are not provided, 360-degree azimuth rotation and zero-degree elevation are assumed. Due to the lack of access to transmitter data, this approach is currently unsuitable in airports, military installations, and US government facilities.

C. Tolerance Threshold Determination Approach

This section describes the approach to determine the threshold suitable for UAM/AMM. This approach initially sets a minimum baseline threshold so the vehicle can tolerate the most common transmitters without avoiding them. Subsequently, the baseline is adjusted upward to accommodate the fewer but more powerful transmitters.

Data for ULS are used for baselining. The transmitters in this database are more numerous and have lower maximum power than other transmitter types. The power maximum is tabulated for each 17 HIRF frequency sub-band and then converted to the equivalent electric field strength at a 100' distance. The baseline threshold is chosen to match or exceed these field maximums.

The baseline threshold is then adjusted upward to account for the higher power sources in the CDBS, IBFS, and weather radar databases. However, the field level should increase only up to a value with an acceptable avoidance zone size and density to avoid overcrowding the space. Outside urban areas, the avoidance zones can be larger in exchange for a lower tolerance level. Weather radar is an example of a transmitter in less populated areas - the corresponding HIRF zones are permitted to be larger than if it is in an urban area. The HIRF-Map approach is then utilized to avoid these HIRF zones.

A vehicle's tolerance level can vary with modulation so it should appropriately match the transmitter's characteristics. The weather radar with pulse transmission should be matched with peak field requirements, while continuous transmission should be matched against field average requirements.

It is noted that ULS's cellular data are old and not updated. Current wireless spectrum owners have up-to-date data, but detailed information is proprietary and usually not available to the public. It is therefore best if a vehicle can tolerate cellular transmitters by default without using the HIRF-Map approach.

III. MINIMUM TOLERANCE RECOMMENDATION RESULTS

The minimum baseline is first established using the ULS database in sub-section A. Adjustments for higher power transmitters are described in sub-sections B, C, and D. The results are summarized in Section IV.

A. Baseline Threshold Based on ULS Database

Fig. 2a shows EIRP versus frequency for over 24,667 ULS-transmitter data records for the New York City area. The area is approximately 40 km (lat.) by 120 km (lon.), centered at the World Trade Center. Note that a transmitter may be associated with several data records, each representing a different combination of frequency, power level, modulation, and other information. Transmitter types are plotted in various colors and markers. They include cellular, land-mobile radios, paging, microwave links, and others. The overall EIRP envelope is plotted for the 17 HIRF sub-bands, with the maximum being as high as 75 kilowatts from a 5G cellular transmitter. That envelope is used to calculate the maximum field strength envelope at the 100' distance shown in Fig 2b. The same data are replotted in Figs. 2c and 2d for better details in frequencies up to 2.5 GHz. The highest field strengths are about 50 V/m associated with a 5G wireless transmitter and about 44 V/m from a microwave link. Below 1 GHz, the field strengths are dominated by land mobile radios

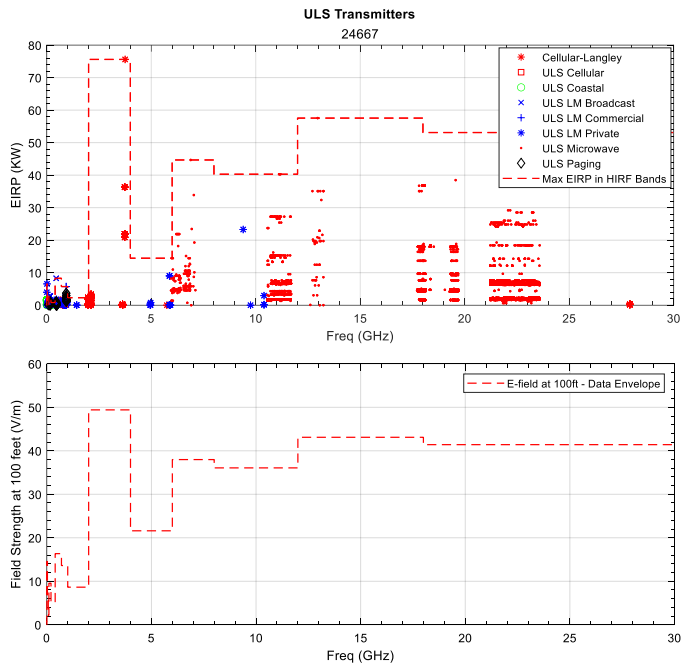
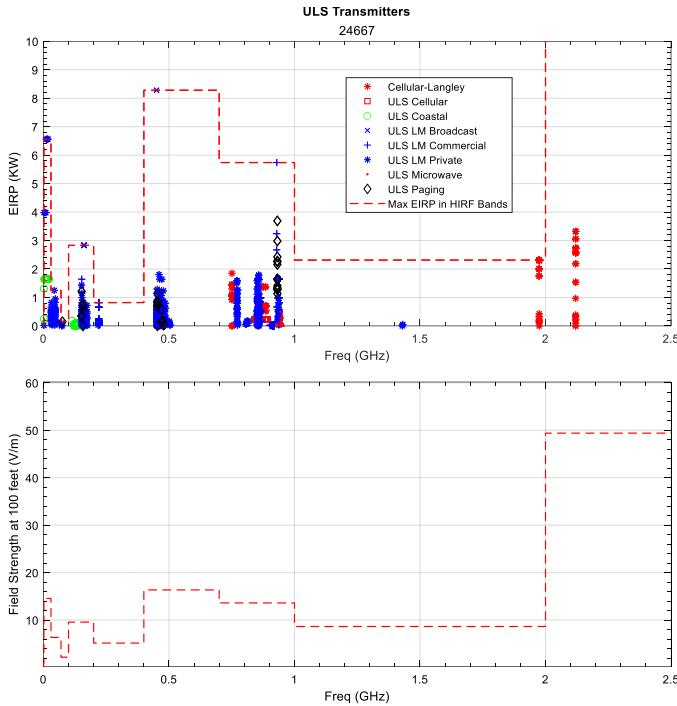


Fig. 2a, 2b: ULS transmitters' EIRP (upper) and field strength envelopes (lower) for frequencies to 30 GHz.

It can be observed that the maximum field levels are less than 25 V/m below 2 GHz and less than 50 V/m above 2 GHz. This implies that these tolerance levels exceed the 100-foot field strengths for all ULS transmitters. For simplicity, these two levels (25 and 50 V/m) are chosen as the baseline threshold in this paper. Even lower thresholds closer to the field strength envelope in Fig. 2b can be set if desired.

As previously noted, detailed wireless/cellular transmitter data are typically proprietary and unavailable to the public. In

this study, limited cellular data for the cities of Hampton, VA, and Columbus, OH are used to establish the baseline field threshold.



Figs. 2c, 2d: ULS transmitters' EIRP (upper) and field strength envelopes (lower) for frequencies to 2.5 GHz.

B. HIRF Threshold for CDBS Transmitters

Fig. 3a shows EIRP for AM (red), FM (blue), and TV (magenta) transmitters and their power envelope. The EIRP maximum can be as high as 50 kilowatts for AM, 65.6 kilowatts for FM, and 8.2 megawatts for TV. The EIRP envelope is converted to field strength at a 100' distance as shown in Fig. 3b. The maximum field strength is 514 V/m driven by the 8.2 megawatts TV station. 631 FCC data records were considered. Fig. 3b also shows the rotorcraft HIRF-Average standard in green for comparison.

The field envelope in Fig. 3b exceeds the HIRF-Average standard above 0.4 GHz (514 V/m versus 200 V/m). This indicates the existing HIRF standard may be insufficient in protecting a vehicle from the most powerful TV transmitters at the standard 100-foot distance. The HIRF-Map approach is a possible solution that can provide the needed additional protection. It is suitable even for vehicles that conform to the current standard levels.

This study recommends a minimum vehicle tolerance threshold to be 40 V/m (500 kHz – 2 MHz), 55 V/m (30 MHz – 100 MHz), and 105 V/m (200 MHz – 1 GHz). These levels are lower than the existing standard, which is a goal. They should sufficiently protect a vehicle up to 400 MHz. From 400 MHz to 1 GHz they are lower than the 100-foot field strength, so the HIRF-Map approach must be used for additional protection.

Fig. 3c shows the HIRF-Map avoidance zones for a 105 V/m tolerance level. The resulting TV HIRF zones are

displayed in magenta. This figure shows that the HIRF zones are few and limited in size, so avoidance is possible with this tolerance value. Though not shown here, a cumulative distribution curve shows 105 V/m exceeds the 100-foot field strength for 70 percent of CDBS transmitters in this region.

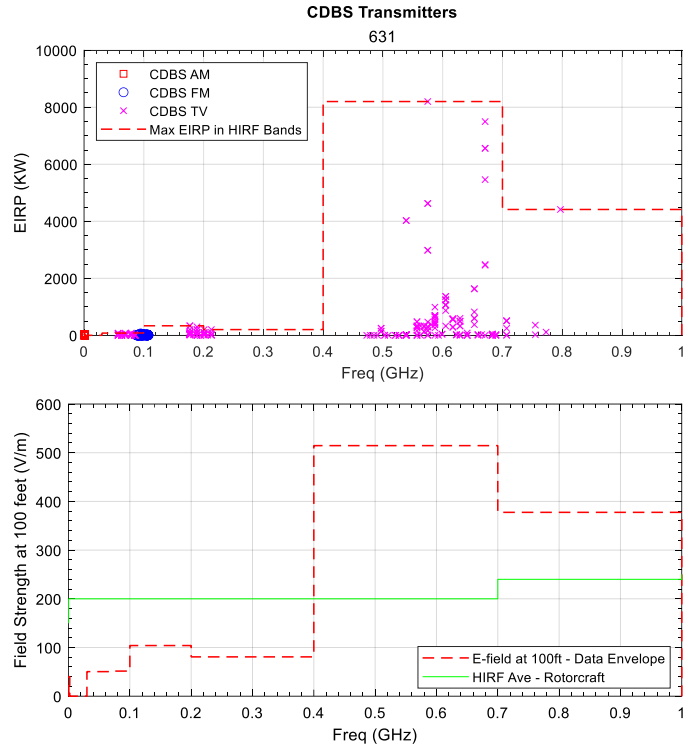


Fig. 3a, 3b: CDBS transmitters' EIRP (upper) and field strength envelopes (lower).

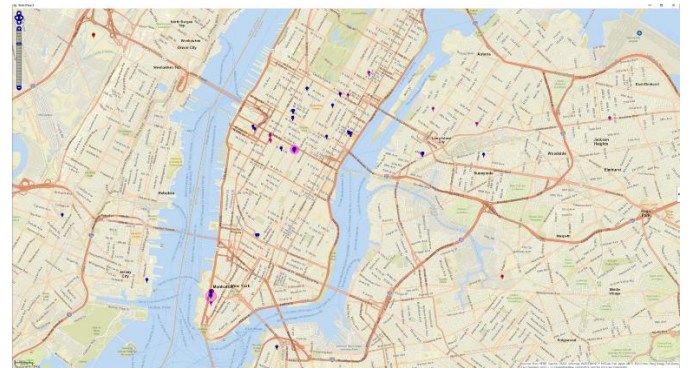


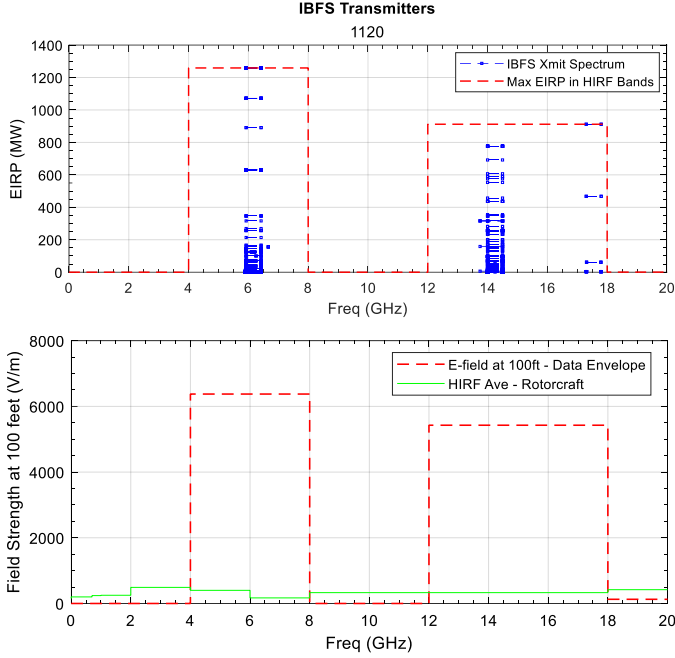
Fig. 3c: TV (magenta) HIRF avoidance zones for 105 V/m thresholds. FM (blue) and AM (red) transmitter locations are also shown.

C. HIRF Threshold for IBFS Transmitters

Figs. 4a and 4b show the EIRP and the 100-foot field strength envelopes for IBFS transmitters, and the comparison against the rotorcraft HIRF-average standard. Fig. 4a shows the maximum EIRP is 1.26 gigawatts. Due to the transmitters' wide bandwidths, EIRP data are displayed as lines rather than markers as with other transmitter types.

Fig. 4b shows the existing rotorcraft HIRF standard being severely inadequate. It is only up to 400 V/m, whereas the field strength envelope is as high as 6,376 V/m between 4-8 GHz. 1120 FCC IBFS data records were considered.

Using the HIRF-Map approach to avoid these IBFS sources in combination with a high vehicle tolerance level is necessary, as a low tolerance threshold would result in large avoidance zones and significantly reduce the remaining vehicle operating space. Fig. 4c shows the resulting avoidance zones for a suggested 500 V/m tolerance level. This level appears to provide reasonable avoidance zone sizes as determined from the map. 500 V/m is higher than the existing rotorcraft HIRF-Average standard and exceeds 42 percent of the 100-foot field strength for the IBFS transmitters in the region.



Figs. 4a, 4b: IBFS transmitters' EIRP (upper) and field strength (lower) envelopes.

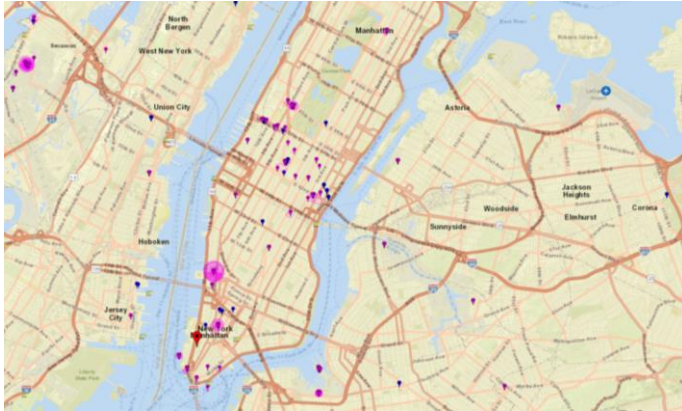


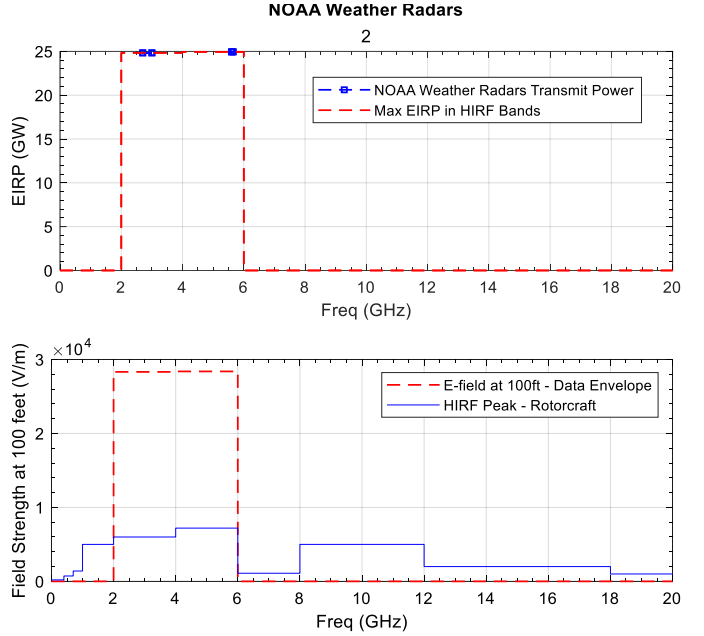
Fig. 4c: IBFS HIRF-Map for 500 V/m suggested tolerance threshold.

D. HIRF Thresholds for NOAA Weather Radar Transmitters

The field strength at a 100-foot distance for NOAA weather radars is 28.4 kV/m as shown in Figs. 5a and 5b. It far exceeds the rotorcraft HIRF Peak standard of 6 kV/m and 7.2 kV/m between 2-6 GHz. So, the existing standard requirements are again not nearly adequate.

Fortunately, there are only 206 of those radars in the entire US. Their locations are known and tend not to be in crowded urban areas. Therefore, having a large HIRF avoidance area is justifiable to lower the vehicle tolerance level. The recommended tolerance is 1000 V/m peak and is far below the standard. The resulting stand-off radius is 866m as shown at the bottom of Fig. 5c.

The field level at 100 feet based on the 46.1 megawatts average EIRP is 1220 V/m (data not shown). The suggested average tolerance level is 50 V/m ($= \sim 1220 \cdot [1000/28,400]$), calculated based on the recommended-to-actual field ratio of 1000/28,400.



Figs. 5a, 5b: NOAA weather radars EIRP (upper) and field strength envelopes (lower).

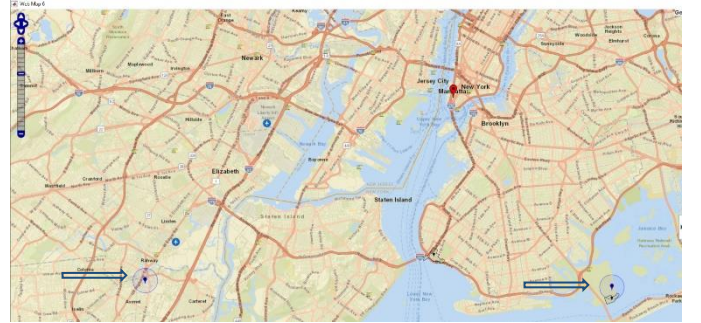


Fig. 5c: NOAA weather radar HIRF zones (blue circles). HIRF zone radius = 866 m for 1000 V/m peak field tolerance level. The city center is in red.

IV. RESULTS SUMMARY

Table I summarizes the recommended tolerance levels in the earlier sections and compares them against the current rotorcraft HIRF standard. The sub-bands are numbered in the first column for easy reference. The HIRF field levels in red in columns 3 and 4 are the existing standard requirements found to be inadequate in this study. The adjacent numbers in blue

are the field strength envelope values that exceed the standard values.

The suggested tolerance levels are shown in columns 5 and 6 and are generally lower than the standard values except for the IBFS system. Wherever the recommended levels are inadequate in protecting against the field environment, the HIRF-map approach is labeled to provide the remaining protection. The last column contains HIRF band drivers. They are transmitter types having the highest EIRP and field strength in each sub-band. For CDBS, the band drivers are more specific whether they are AM, FM, or TV.

It is reasonable to claim that this HIRF-map approach provides better protection than the original HIRF standard, even with the lower suggested vehicle tolerances. This is achieved by having accurate and up-to-date data on local high-power transmitters, including those not previously accounted for such as satellite uplink transmitters, weather radars, and some TV stations. The HIRF-Map approach may allow a vehicle to be closer to a transmitter than the 100 feet assumed in the standard. The determination can be made in real-time knowing the vehicle tolerance level and the transmitter's EIRP.

This approach can also provide additional protection to existing and future vehicles certified to the current standard. This is achieved by limiting exposure to the HIRF environments that are higher than the standard.

This current study excludes airports, governmental facilities, and military installations. A vehicle with a lower tolerance than the HIRF standard should avoid these areas unless transmitter data are available.

Other urban areas may be analyzed in future efforts, and modifications to the suggested tolerance levels may result. The same approach may apply to countries outside of the U.S.

TABLE I. HIRF STANDARD vs. SUGGESTED THRESHOLD

HIRF Standard				Suggested Tolerance Level		
HIRF Bands	Freq. Range	Rotorcraft Peak	Rotorcraft Ave	Peak	Ave	Band Driver
1	10 kHz - 100 kHz	150	150		25	ULS
2	100 kHz - 500 kHz	200	200		25	ULS
3	500 kHz - 2 MHz	200	200		40	CDBS/AM
4	2 MHz - 30 MHz	200	200		25	ULS
5	30 MHz - 70 MHz	200	200		55	CDBS/TV
6	70 MHz - 100 MHz	200	200		55	CDBS/TV
7	100 MHz - 200 MHz	200	200		105	CDBS/TV
8	200 MHz - 400 MHz	200	200		105	CDBS/TV
9	400 MHz - 700 MHz	730	200 (515)		105 + Map	CDBS/TV
10	700 MHz - 1 GHz	1400	240 (378)		105 + Map	CDBS/TV
11	1 GHz - 2 GHz	5000	250		25	ULS
12	2 GHz - 4 GHz	6000 (28,400)	490 (1220)	1000 + Map	50 + Map	NOAA, NOAA
13	4 GHz - 6 GHz	7200 (28,400)	400 (6376)	1000 + Map	500 + Map	NOAA, IBFS
14	6 GHz - 8 GHz	1100	170 (6376)		500 + Map	IBFS
15	8 GHz - 12 GHz	5000	330		50	ULS
16	12 GHz - 18 GHz	2000	330 (5427)		500 + Map	IBFS
17	18 GHz - 40 GHz	1000	420 (127)		125, or 50 + Map	IBFS, ULS

V. CONCLUSIONS

A minimum threshold for HIRF tolerance is suggested. This threshold is generally lower than the existing standard and can help reduce vehicle and certification expenses. When coupled with HIRF transmitter maps, it can protect a UAM/AAM vehicle from high-power HIRF sources, including those not previously considered in the current standard.

ACKNOWLEDGMENTS

This work was sponsored by the NASA System-Wide Safety Project and the Electrified Powertrain Flight Demonstration Project.

Matlab Web Map and Google Maps were used in the figures. More information can be found in [10,11].

REFERENCES

- [1] SAE ARP 5583A, Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment, June 2010.
- [2] High-Intensity Radiated Fields (HIRF) Protection for Aircraft Electrical and Electronic Systems, A Rule by the Federal Aviation Administration on 08/06/2007, 72 FR 44015, Docket No. FAA-2006-23657.
- [3] AC 20-158B, The Certification of Aircraft Electrical and Electronic Systems for Operation in a High-Intensity Radiated Field (HIRF) Environment, May 20, 2014, Federal Aviation Administration.
- [4] Urban Air Mobility (UAM) Concept of Operation (ConOps) v2.0, April 26, 2023, Federal Aviation Administration.
- [5] HIRF requirements applicability to new urban flying vehicles, SC 2016-004. EASA – EUROCAE Framework Contract N°EASA.2016.FC19
- [6] Nguyen, T., “High-intensity radiated field (HIRF) map - An avoidance approach for UAM, AAM, and UAS Vehicles,” DASC Conf. 2023.
- [7] Matlab. <https://www.mathworks.com>
- [8] FCC Databases. <https://www.fcc.gov>.
- [9] <https://www.ncei.noaa.gov/products/radar>;
<https://www.roc.noaa.gov/WSR88D/Engineering/NEXRADTechInfo.aspx>
- [10] Sources for Matlab's Web Map: Esri ArcGIS Online (Tiles), Esri, HERE, DeLorme, Garmin, TomTom, USGS, Intermap, iPC, INCREMENT, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, OpenStreetMap, the GIS User Community, MapmyIndia, GEBCO, FAO, NPS, GeoBase, IGN, KadasterNL, DigitalGlobe, Earthstar Geographic, CNES/Airbus DS, GeoEye, USA FSA, Getmapping, Aerogrid, IGP, swisstopo, and others. The OpenStreetMap license is available at: <https://www.openstreetmap.org/copyright>
- [11] Google Maps: <http://map.google.com>