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HIRF Avoidance for VTOL/AAM Vehicles

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August 2025

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Executive Summary

The need to protect air vehicles from High-Intensity Radiated Fields (HIRF) has increased substantially in recent years due to several factors: greater reliance on digital electronics, reduced inherent shielding in modern airframe designs, higher data and processor speeds, broader frequency spectrum usage, and the growing density of transmitters. Common HIRF sources include radars, broadcast towers, satellite communication uplinks, and microwave links. Traditional approaches to HIRF protection require costly shielding and filtering measures, particularly for rotorcraft and advanced air mobility (AAM) vehicles, which operate closer to ground-level transmitters. This paper proposes a cost-effective alternative: a HIRF avoidance strategy using geographic "HIRF-maps". Instead of designing vehicles to meet the stringent HIRF tolerance levels defined by rotorcraft standards, this approach allows for lower vehicle tolerance levels - provided they maintain safe standoff distances from known transmitter sources.

The proposed method calculates these avoidance distances based on each vehicle's electromagnetic tolerance and the power output of nearby transmitters. The concept was demonstrated using MATLAB and government transmitter databases to generate HIRF-maps highlighting risk zones for flight planning. These maps can be integrated into navigation tools to guide AAM operations away from high-intensity fields.

This approach is well suited for civilian AAM applications in both urban and non-urban airspaces. It prioritizes affordability, flexibility, and safety by relying on informed avoidance rather than overengineering. Field data from major cities such as New York indicate that some urban environments significantly exceed standard HIRF levels, highlighting the need for customized tolerance thresholds and avoidance protocols.

A key contribution of this paper is the recommendation of urban tolerance thresholds to support AAM vehicle certification and flight planning. Based on transmitter data and maps from twelve major U.S. cities, a minimum tolerance level is proposed that enables vehicles to withstand most common transmitters, limiting the need for avoidance maps to only the most powerful emitters. Outside urban areas, HIRF avoidance is generally simpler due to lower transmitter density; however, vehicles may still encounter high-power pulsed sources such as weather, aviation, and military radars. The paper also recommends a peak vehicle tolerance level and corresponding stand-off distances based on emitter locations.

The proposed avoidance framework offers a software-based mitigation strategy that reduces the need for heavy shielding while supporting compliance with HIRF certification requirements. It can be integrated into flight control and navigation systems to help plan HIRF-aware routes in real time or during pre-flight planning. This innovation improves operational flexibility, reduces costs, and enhances safety for AAM operations, particularly in dense urban environments where electromagnetic congestion is highest.

1 Introduction

Airborne vehicles can be susceptible to electromagnetic interference and potential damage from high intensity radiated fields (HIRF) generated by high-power transmitters. This interference can result in the loss of critical vehicle functions or controls. The need to protect aircraft systems from HIRF has grown in recent years due to several factors: the increased reliance on digital electronics, reduced shielding in aircraft designs, higher data and processor speeds, expanded frequency spectrum usage, and a rise in the number of transmitters [1].

HIRF sources include systems such as radars (used in weather monitoring, at airports, on ships and aircraft, etc.), terrestrial and satellite uplink transmitters, radio and TV towers, and microwave links, among others. AM/FM/TV radio antennas can broadcast hundreds of thousands of watts of effective radiated power. Radars, satellite uplinks, and microwave communication antennas can concentrate energy into narrow beams, significantly increasing field intensity. HIRF threats also extend to wireless towers, especially 5G transmitters having high gain antennas. Additionally, user equipment like cellular phones and portable two-way radios, when used near sensitive systems, can pose interference risks.

Typical airborne vehicles, including aircraft and rotorcraft, are tested to HIRF standards to ensure compliance with regulatory requirements [1-4]. The HIRF environments for aircraft are predominantly influenced by transmitters located near large airports, where aircraft are closest to the ground and thus at greater risk of exposure to high-intensity fields. The HIRF environments for aircraft were calculated based on typical flight paths at several representative airports in the US and Europe, with considerations also given to military transmitters.

The HIRF environment for rotorcraft is more severe than that for fixed-wing aircraft due to their closer proximity to the ground during normal operations, which increases the likelihood of direct illumination by ground transmitters. Exposure field strength can reach up to 7200 V/m peak and 490 V/m average [1-5]. Additionally, rotorcraft often have less metal shielding compared to aircraft. As a result, protecting helicopter systems from HIRF can be costly due to the high level of field exposure.

Advanced Air Mobility (AAM), Urban Air Mobility (UAM), Vertical Takeoff and Landing (VTOL) vehicles, and Unmanned Aircraft Systems (UAS) may operate in HIRF environments like those encountered by helicopters. These vehicles can hover close to the ground, increasing their exposure to direct illumination by ground transmitters. It is anticipated that they may be required to meet the HIRF environment derived from the standards for rotorcraft. Protection against severe HIRF environments could lead to increased vehicle costs, size, and weight. Low-cost constructions with minimal shielding and filtering may struggle to meet standard certification requirements. For simplicity, this paper refers to AAM as encompassing AAM, UAM, UAS, and VTOL.

This paper presents a novel approach to reducing the cost of vehicle HIRF protection while maintaining a comparable level of safety. It introduces the concept of a HIRF avoidance map as an alternative strategy to traditional certification methods [6] (U.S. Patent Application No. 18/617,802). Instead of designing vehicles to withstand the HIRF environments prescribed by helicopter standards, this approach enables the use of a lower tolerance level - provided the vehicle avoids areas of high electromagnetic exposure by maintaining safe distances from high-power transmitters.

Lowering the required HIRF tolerance level has the potential to reduce vehicle cost, size, and weight. However, this strategy relies on two key inputs: an understanding of the vehicle's electromagnetic tolerance, and a knowledge of transmitter locations and radiation characteristics. With this information, safe standoff distances and corresponding avoidance zones can be calculated and visualized on maps to define operational boundaries, ensuring that the vehicle remains within safe exposure limits. This methodology is referred to throughout the paper as the “HIRF-map” concept. Figure 1-1 illustrates the approach, showing a sample flight path that navigates around HIRF avoidance zones highlighted in red.

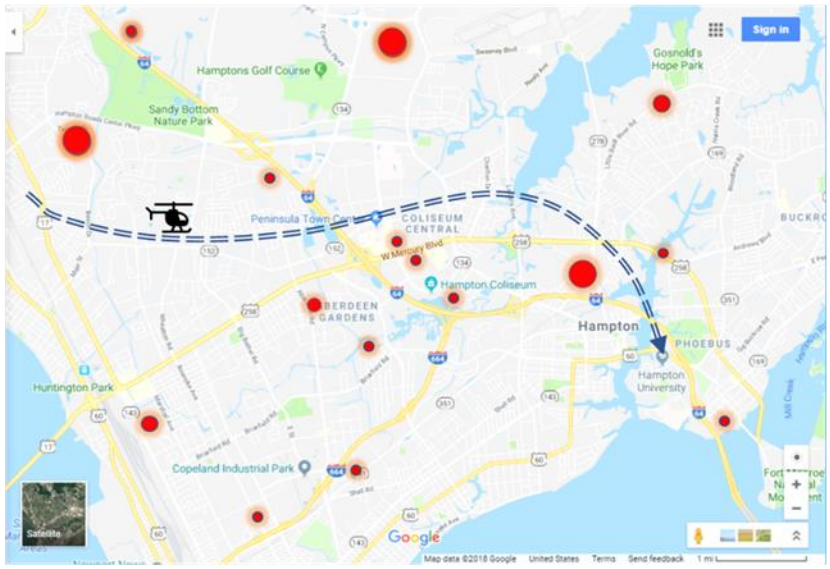


Fig. 1-1: Illustration of planning flights around HIRF transmitters. (Credit: Google Maps)

Efforts to limit air vehicle exposure to High-Intensity Radiated Fields (HIRF) are already in place in some areas. In the United Kingdom, the UK Ministry of Defence operates the High-Intensity Radio Transmission Area (HIRTA) system that designates airspace where radio energy may interfere with equipment on air vehicles, including helicopters. The HIRTA system was introduced to address low-level flying at a time when the HIRF threat to aircraft was not fully addressed. To mitigate these risks, each transmitter that exceeds a specified effective isotropic radiated power (EIRP) threshold is identified, and avoidance distances and heights are specified and published for aircraft for various aircraft clearance levels. While the process addresses the protection of military aircraft, all civil and military transmitters are captured and monitored, including radio and TV broadcast transmitters, satellite communication ground stations, and radars.

The documentation is updated monthly and typically around ten significant new or modified transmitters are identified each quarter. Some significant transmitters are introduced in urban areas and few of these can generate HIRF environments that exceed HIRF Environment I at 1000 ft. Further, the HIRTA system addresses operation over built-up areas and rural areas. The minimum EIRP does, however, mean that transmitters such as mobile phone masts do not appear as they do not represent a threat to military aircraft.

In contrast to the HIRTA concept, the HIRF-map concept emphasizes cost reduction, particularly for commercial VTOL and other AAM vehicles operating in challenging environments such as densely populated urban areas with high concentrations of powerful transmitters. This cost reduction is achieved by allowing lower individual vehicle tolerance levels than those specified in the standard. The tradeoff is that, when necessary, a vehicle may need to maintain a greater distance from a transmitter than the standard 100 feet. Under this concept, vehicle designers can choose to balance the cost efficiency of lower tolerance levels against the operational flexibility offered by higher ones. Additionally, this paper recommends a suitable minimum vehicle tolerance level based on HIRF environments in major urban areas. The approach is also applicable in non-urban areas, where the lower density of HIRF transmitters makes avoidance significantly easier.

The benefits of this concept are difficult to quantify at this stage but could be substantial, depending on the selected tolerance levels. First, lowering the HIRF protection threshold below current standards could significantly reduce costs by minimizing the number and strength of required protection components. These may include external elements such as conductive-mesh composite fairings, airframe and window shielding, as well as internal elements like LRU shielding, filtered connectors, RF gaskets, shielded wiring, raceways, bonding jumpers, and filter capacitors.

Second, adopting a lower HIRF threshold may permit the use of existing avionics certified to less stringent levels, thereby shortening development time, and lowering overall program costs. Third, reduced protection requirements could influence broader vehicle and system design decisions, freeing space, reducing weight, and potentially improving fuel efficiency, payload capacity, and operational flexibility.

Finally, this approach enhances safety in two keyways. First, it supports adaptability by using transmitter databases that can be updated daily, allowing vehicles to respond to changing and evolving conditions rather than relying on static assumptions. Second, it benefits vehicles already certified to existing standards by enabling them to avoid regions where field strengths exceed those limits. Sections 3 and 4 present examples where transmitter environments significantly surpass the standard rotorcraft HIRF exposure levels.

For the remainder of this paper, Section 2 describes the HIRF avoidance concept and its implementation. It includes calculations of the HIRF avoidance radius and discusses transmitter databases suitable for urban environments. Example map outputs are provided. Additionally, the section briefly addresses other transmitters relevant to HIRF considerations, including surveillance radars, marine radars, vessel traffic services, experimental transmitters, and high-frequency broadcasting systems.

Section 3 examines the HIRF environment in New York City, serving as a representative urban area where AAM/VTOL operations are anticipated. It characterizes the electromagnetic landscape by calculating electric field strengths from known transmitters identified in various regulatory databases and compares these values to existing HIRF standards.

While the HIRF-map approach can theoretically accommodate very low tolerance thresholds, setting the threshold too low may lead to overly large and impractical avoidance zones, particularly in congested airspace. To ensure both safety and operational feasibility, this section proposes a minimum recommended vehicle tolerance level that enables manageable avoidance regions.

Section 4 expands upon the analysis presented in Section 3 by including urban areas in eleven additional cities. The worst-case HIRF field environments in these locations are tabulated and compared against both New York City and the existing standards. Based on this broader dataset, the minimum tolerance level initially proposed for New York City is refined to account for the additional environmental conditions observed across these cities.

Section 5 includes data on common radar systems used for civilian applications in the U.S., along with proposed peak vehicle tolerance levels to protect against these sources. For reference, data for several representative military radars are provided.

Appendix A provides examples of TV transmitter data for three major U.S. cities, sourced from a newer FCC database that replaces the legacy system used in this paper, which is no longer being maintained. Future revisions of the HIRF-map tool should incorporate data from this updated database.

Appendix B presents transmitter data for high-frequency (HF) broadcasters within the U.S. and its territories, serving as an example of additional transmitter types that could be integrated into the database beyond those analyzed in Sections 3 and 4.

Radars can emit high-power signals that result in large avoidance zones. Powerful weather radars near airports may have large avoidance zones, potentially restricting future VTOL operations at those locations. Appendix C provides a list of U.S. airports with nearby weather radars. To mitigate these restrictions, vehicle tolerance levels may be increased to reduce the size of the required avoidance zones where VTOL operations are expected.

The concept discussed in this paper was first publicly introduced in [7–9]. Building on those earlier works, this paper provides updated analyses, extends the HIRF environmental data coverage beyond the previously reported New York City region, and presents new data on pulsed radar systems in Section 5 that were not included in prior publications. It also offers a more detailed discussion that was not possible in the earlier papers due to their shorter format.

2. HIRF Avoidance Method

The key principle of this approach is that the vehicle must maintain sufficient distance from any high-power transmitter so that the resulting field strength does not exceed the vehicle's tolerance level. Let E_T (in V/m) represent the vehicle's HIRF tolerance, determined through testing or design specifications. This tolerance may be set arbitrarily lower than the regulatory standard (or higher if the anticipated environment exceeds the standard). Let P_T be the transmitter's Effective Isotropic Radiated Power (EIRP), in watts. By equating the power density corresponding to the vehicle's tolerance level (derived from E_T) to the power density from the transmitter at a distance R in meters, the minimum required standoff distance R can be solved:

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

$$R \;>\; (30 * P_T)^{1/2}/\,E_T \qquad \text{Eq. (1)}$$

A map is then developed to delineate the region within the radius R from the transmitter for avoidance. Map regions outside of radius R are considered to pose a low interference risk and are deemed acceptable for vehicle operation. It is important to note that a vehicle's HIRF tolerance may vary with frequency and modulation characteristics; therefore, the appropriate tolerance level should be selected based on the specific parameters of each transmitter.

This section is organized as follows: Subsection 2.1 provides a brief overview of the HIRF-map concept and its implementation using MATLAB [10]. Subsection 2.2 describes U.S. transmitter databases that may be relevant to operations in urban areas. Subsection 2.3 presents example outputs generated by the HIRF-map tool. Subsection 2.4 discusses additional emitters that could impact AAM operations outside of urban areas. Finally, Subsection 2.5 discusses key findings and conclusions related to the concept.

2.1 HIRF-map Implementation and Demonstration

The steps for generating a HIRF-map include:

- Import transmitter databases from regulatory sources and identify transmitters within the area of interest.
- Determine the AAM vehicle's HIRF tolerance level, through testing and/or requirements.
- Compute HIRF-map radii based on the transmitters' power levels and the vehicle's HIRF tolerance levels.
- Overlay the HIRF-map calculations onto commercial maps.
- Mark HIRF regions for flight planning.

Key elements in the process are illustrated below in Fig. 2-1. Green boxes denote input data, blue boxes indicate calculations, and the gold box represents two-way interactions with flight planning tools. Regions outside of radius R from the transmitter are considered to have a lower interference risk. Conservative calculations should use the worst-case antenna direction, gain, and power data.

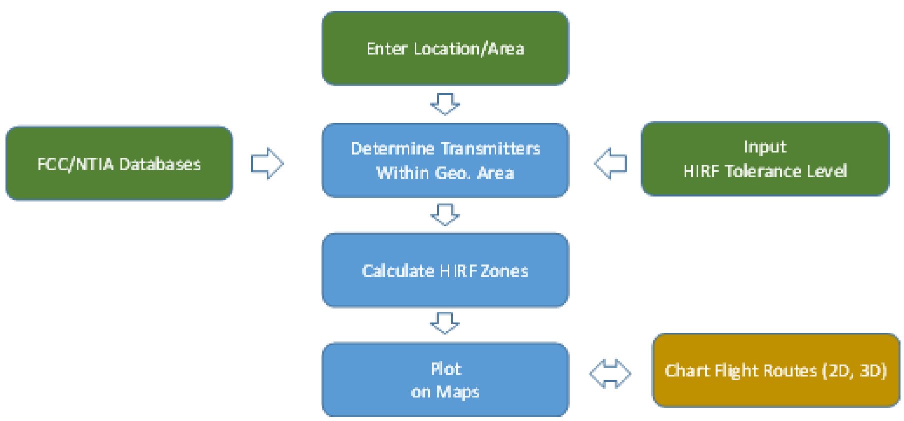


Fig. 2-1: HIRF avoidance process

2.2 Transmitter Databases

The most critical component of this approach is having access to accurate and up-to-date transmitter databases. This can be challenging, as many data sources are not publicly available due to security or proprietary concerns. For this demonstration, the paper primarily relies on publicly accessible data, and includes Federal Communications Commission (FCC) databases [11] and the National Oceanic and Atmospheric Administration's (NOAA) weather radars [12]. Additional databases can be incorporated if access becomes available.

In the US, the FCC maintains the largest publicly available transmitter databases. The databases are organized into three systems: the Consolidated Database System (CDBS), which has recently transitioned to the Licensing and Management System (LMS), the International Bureau Filing System (IBFS), and the Universal Licensing System (ULS). Public files from these systems are updated at least weekly, often daily. The database structures are well-documented.

The CDBS after the transition to the LMS is no longer updated with new data after October 2023. Similarly, the IBFS system has transitioned to the International Communications Filing System (ICFS). The LMS and ICFS are the FCC's modernized platform to manage and process applications for various radio service licenses. They provide an online portal for public users and staff to access, search, and process licensing data. Applications and modifications for licenses can be processed in real-time, allowing for quicker issuance and updates to licenses for broadcasters and other users of the radio spectrum. The LMS databases should contain the same data as the CDBS but will continue to be updated after 2023. Similarly, ICFS will continue to be updated going forward. Data from the earlier CDBS and IBFS are used in this paper's demonstration without loss of generality, although the newer databases should be used in actual flight planning applications for up-to-date information.

The FCC databases and NOAA weather radars are described below. It is important to note that FCC databases report spectrum licenses but do not indicate whether a transmitter is actively operating at any given time, leading to more conservative assessments.

A. FCC CDBS and LMS Databases

The CDBS and LMS databases maintain detailed records on AM, FM, and TV broadcast services. Key data used in generating HIRF avoidance maps include frequency, power, antenna gain, and GPS location. For mapping purposes, power data—provided as Effective Radiated Power (ERP) for FM and TV stations or as field strength at a specified distance for AM stations—are first converted to Equivalent Isotropic Radiated Power (EIRP) before calculating the safe distance R using Eq. 1. To ensure a conservative approach, data corresponding to the direction of maximum field strength are used in these calculations.

Both CDBS and LMS include historical transmitter data for analog TV, which is now obsolete and no longer authorized for transmission in the U.S. Therefore, only digital TV data are considered when recommending vehicle tolerance levels Section 3.

It is noted that GPS data in the CDBS are often truncated to the nearest second, introducing location uncertainties of up to 30 meters. In contrast, the modernized LMS system generally rounds GPS coordinates to the nearest 1/10 of a second, offering improved accuracy. This improvement is due to more precise GPS data being entered as licenses are renewed. As a result, GPS precision is expected to no longer be a concern with the LMS system.

B. FCC IBFS Database

The IBFS database contains information on international and satellite applications and licenses. Relevant to this study are satellite earth stations, where high-power transmitters on the ground communicate with satellites overhead. Although the actual radiated powers of these transmitters are significantly lower than those of TV transmitters, their antennas often have high gains and narrow beam widths - typically 2 degrees or less - resulting in EIRPs that can exceed 1 billion watts.

Conservative calculations are used to account for incomplete data in the database. When elevation data are available, the radius of the HIRF zone is reduced by multiplying it by the cosine of the elevation angle. If angular data are provided, the HIRF zones are modeled as smaller, fan-shaped regions corresponding to the transmitters' potential scanning ranges. In the absence of such data, a worst-case scenario is assumed - zero-degree antenna elevation and a 360-degree azimuth steering range - resulting in circular avoidance regions.

C. FCC ULS Databases

The Universal Licensing System (ULS) encompasses about a dozen of databases that cover various services. The list below contains services utilized in the calculation of High-Intensity Radiated Field (HIRF) maps. There are other services, including amateur radios, that are unsuitable due to the lack of necessary location or power data.

The Universal Licensing System (ULS) comprises approximately a dozen databases covering various communication services. The list below identifies the services used in calculating High-Intensity Radiated Field (HIRF) maps. Other services, such as amateur radio, are excluded due to their low transmit power or the lack of sufficient location or power data.

- Land Mobile (Broadcast Auxiliary, Commercial, and Private)
- Maritime Coast & Aviation Ground
- Microwave
- Paging
- Broadband Radio Service (BRS) & Education Broadband Service (EBS)
- Market-Based Services
- Cellular

The FCC no longer maintains or updates data on cellular transmitters. Instead, this information is managed internally by wireless service providers and is considered proprietary. As a result, HIRF avoidance strategies cannot be applied to these sources. Vehicles should therefore be designed with sufficient tolerance to withstand exposure to wireless transmissions without relying on avoidance measures.

When available, antenna characteristics such as beamwidth, orientation, and scan angle are incorporated into the construction of HIRF zones; microwave transmitters are one such example. It is also noted that GPS data in the ULS databases are not rounded, allowing for precise transmitter location mapping.

D. NOAA Weather Radar

The transmitter list includes 46 Terminal Doppler Weather Radars (TDWR) and 160 Next-Generation Weather Radars (NEXRAD) from NOAA [12]. These radars are assumed to operate with 360-degree azimuth rotation and zero-degree elevation angle, with an estimated peak radiated power of approximately 24.83 billion watts EIRP. Relevant technical data are summarized in Table 2.1.

TABLE 2-1: NOAA’s TDWR and NEXRAD weather radars

	NEXRAD (WSR-88D) # = 160	TDWR # = 46
Frequency	2700-3000 MHz	5600-5650 MHz
Peak Power	700 kW**	250 kW**
Average Power	300-1300 W	
Antenna Gain	45.5 dB	50 dB
EIRP (Peak)	103.95 dBW (24.83 GW)	103.97 dBW (24.83 GW)
EIRP (Ave)	76.64 dBW	
Beam Width	0.925 degrees	0.55 degrees
Pulse Width-max	1.57 & 4.7 microsec	1.1 microsec

** Maximum klystron output power. Antenna cable loss = 0 dB is assumed as the worst case (installation dependent).

2.3 HIRF Avoidance Map Examples

Various graphical tools, including MATLAB's Web Map and Google Maps, are used to illustrate examples of HIRF avoidance zones associated with transmitters from the CDBS, IBFS, ULS, and NOAA weather radar databases. Each data layer can be toggled on or off, and zoom functionality enables detailed inspection. The maps also display markers and boundaries for airports, helipads, and military bases. Black-shaded areas indicate avoidance zones related to non-HIRF concerns, such as security or collision risks. Helipads, shown with yellow helicopter icons, are highlighted due to their potential relevance to AAM and VTOL operations. In these examples, vehicle tolerance levels are intentionally set low to enlarge the avoidance zones, enhancing their visibility on small-scale maps.

A. CDBS Database Example

Examples of HIRF zones for CDBS transmitters are shown in Fig. 2-2 for a small area in Corpus Christi, Texas. The vehicle tolerance level is set at 10 V/m across the band. Small red, blue, and magenta markers, along with their surrounding shaded circles, represent the locations and HIRF zones of AM, FM, and TV transmitters, respectively. HIRF zones for AM and FM transmitters are generally much smaller than those for TV transmitters, so the map may need to be enlarged for clear visibility. Each circle on the map corresponds to the HIRF zone associated with a specific frequency channel or station. Multiple stations may share a transmitter location, as indicated by concentric circles that appear as darker shaded regions. Additional information about each transmitter is available by selecting its marker in the tool.

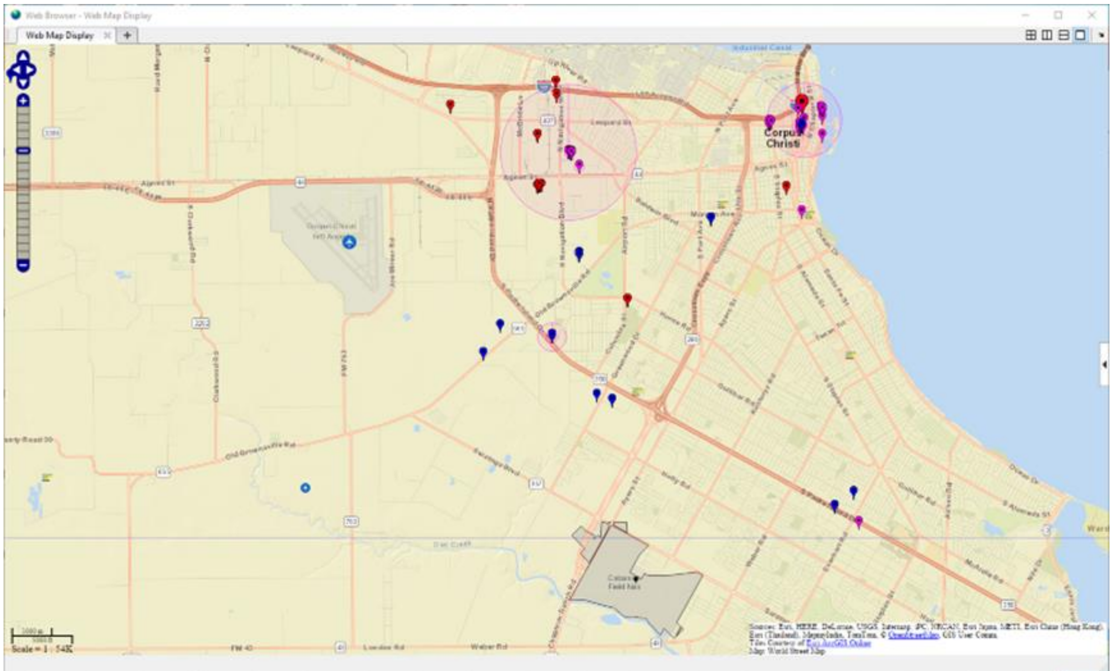


Fig. 2-2: AM, FM, and TV HIRF-map example.

B. IBFS Database Example

Fig. 2-3 shows IBFS transmitter locations and their associated HIRF zones at a 50 V/m tolerance level, which is intentionally set low to enhance visibility on the map. The figure displays HIRF zones for transmitters with available frequency coordination data from the FCC database, incorporating antenna angular range and elevation angle to produce fan-shaped zones. Approximately 50% of the transmitters in the IBFS database include this coordination data. For transmitters lacking such information, worst-case assumptions are applied - specifically, a zero-degree elevation angle and 360-degree azimuth coverage - resulting in circular HIRF zones. As with the CDBS, GPS data in the IBFS database are truncated to the nearest second.

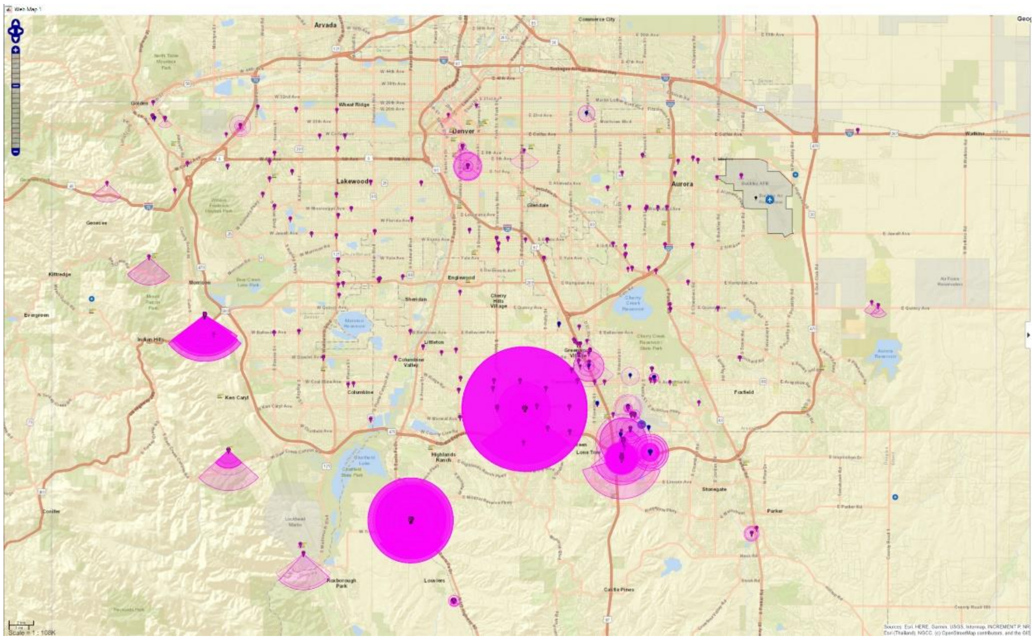


Fig. 2-3: Example of IBFS HIRF avoidance zones.

C. ULS Databases

Fig. 2-4 presents an example of ULS transmitters near Hampton, Virginia. The data sources include Cellular, Microwave Link, Land Mobile (Commercial, Broadcast, and Private), Maritime Coast & Aviation Ground, and Paging databases. Fig. 2-5 provides a zoomed-in view of one of the HIRF zones, along with a satellite image overlay. Markers indicate transmitter locations and their corresponding HIRF zones, with different colors representing the source database. Microwave links appear as narrow pencil beams. It is also noted that cellular data in the ULS are incomplete and do not reflect the actual number of ground-based transmitters, which is significantly higher.

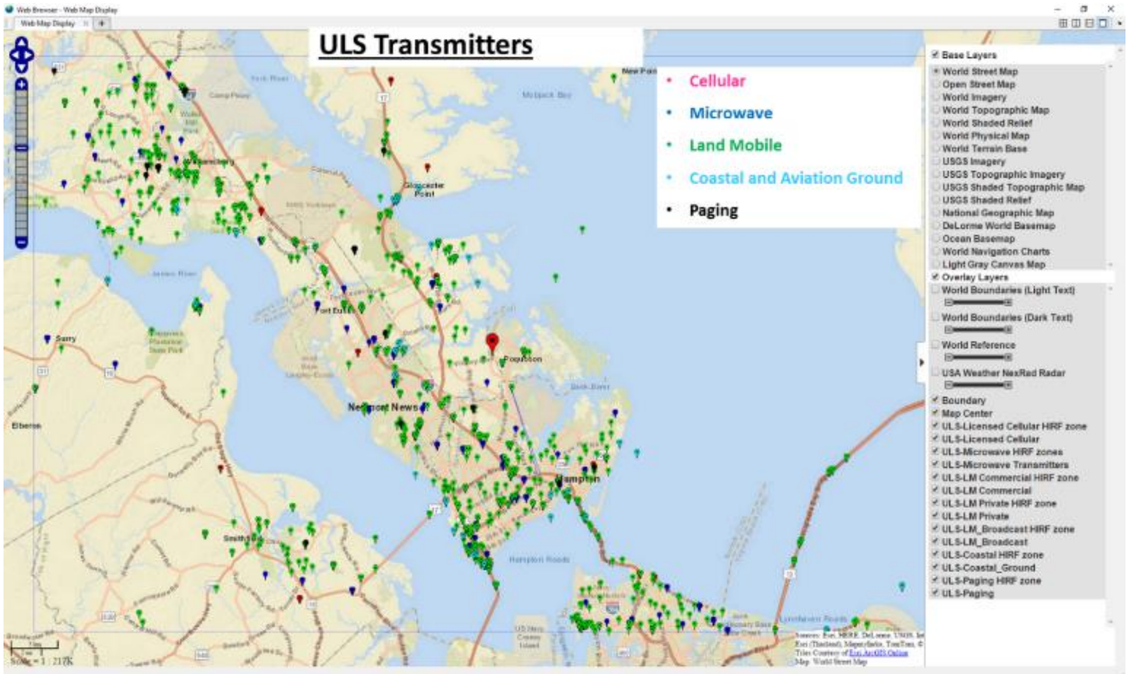


Fig. 2-4: ULS transmitters near Hampton, VA region.

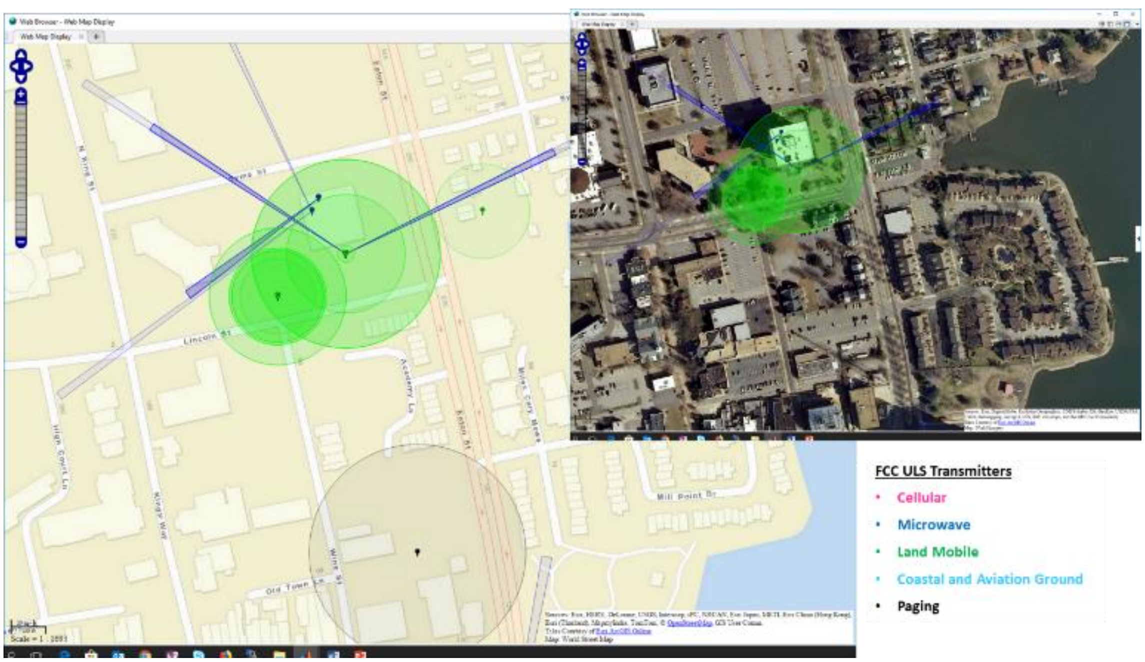


Fig. 2-5: Expanded view of ULS transmitters HIRF zones. 5V/m vehicle tolerance level.

D. NOAA Weather Radar

Fig. 2-6 provides an overview of NEXRAD and TDWR transmitter locations across the U.S. Fig. 2-7 illustrates the HIRF zone of a TDWR radar near Corpus Christi, Texas, based on a 1000 V/m tolerance level.

Fig. 2-6: NOAA weather radar locations.

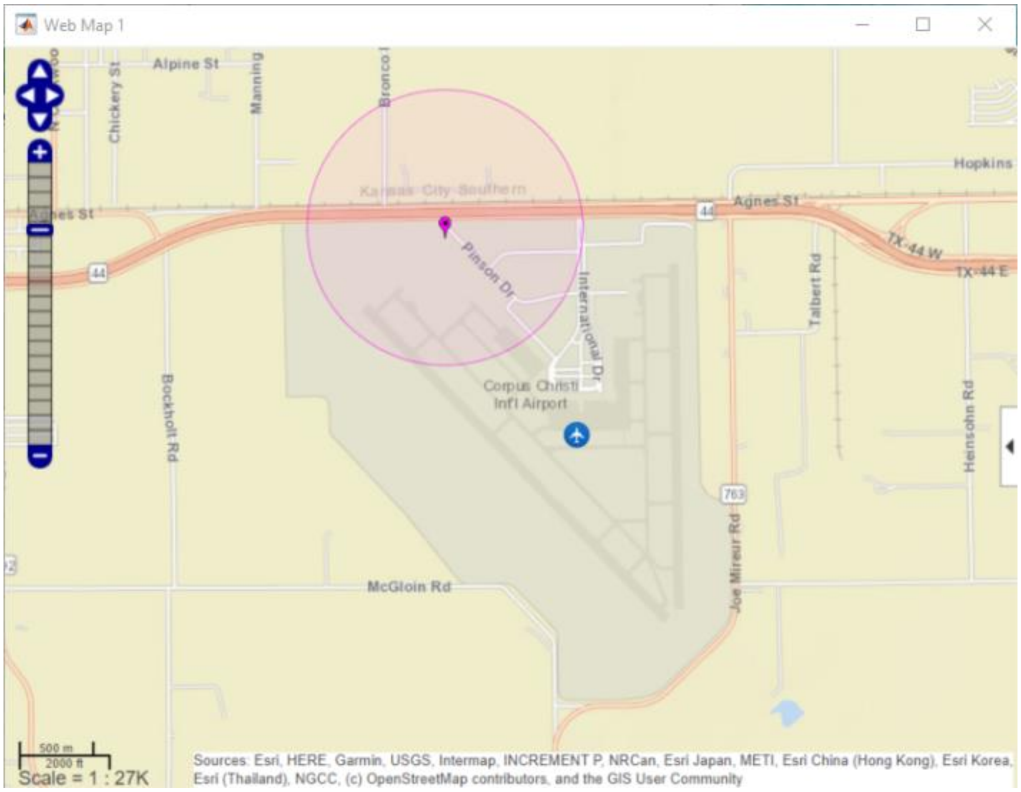


Fig. 2-7: TDWR HIRF avoidance zone for 1000 V/m tolerance level.

2.4 Other Transmitters

Many other high-power transmitters are not examined in detail in this paper. While the study aims to be comprehensive and focuses on transmitters most likely to affect VTOL and AAM operations in the U.S., it does not attempt to account for all transmitters worldwide. Some of these additional transmitters are briefly discussed below.

- **NTIA database**

High-power transmitter data managed by the National Telecommunications and Information Administration (NTIA) and the Federal Aviation Administration (FAA) are of interest. The NTIA oversees spectrum usage for the U.S. federal government, including military applications, while the FAA manages transmitters critical for safe airspace operations. Due to restricted public access, these databases are not currently integrated into the HIRF-map tool.

- **Surveillance radars**

This category includes Common Air Route Surveillance Radar (CARSR), Air Route Surveillance Radar (ARSR), Secondary Surveillance Radar (SSR), Airport Surveillance Radar (ASR), Joint Surveillance Systems (JSS), and others. The peak power of newer solid-state ARSR models can reach up to 65 kW. With an antenna gain of 30 dB, this translates to an EIRP of approximately 130 MW. Unverified CARSR, ARSR, SSR, and JSS transmitter location data found online have been incorporated into the HIRF-map tool for evaluation. Most of these high-power radars are in rural or less populated areas, on government properties, or within airport boundaries where access is likely restricted. As a result, avoidance is generally straightforward since these radars are not situated in regions crowded with other high-power transmitters. It is also noted that many radar sites are listed under multiple classifications—such as ARSR, JSS, and CARSR—due to their overlapping roles in air traffic control and national defense, as well as the reclassification of many ARSR and JSS sites as CARSR following FAA modernization upgrades.

A map of surveillance radars (CARSR, ARSR, SSR, and JSS), along with the 200 previously discussed NOAA weather radars, is provided in Section 5. The data indicate that these radars are limited in both number and geographic concentration, and they do not pose a significant concern for VTOL operations if safe separation distances are maintained.

Other surveillance radars may present HIRF concerns for VTOL vehicles. One example is the Upgraded Early Warning Radar (UEWR) system and its earlier variants. The UEWR system includes only three transmitter sites in the United States, with two additional locations in the United Kingdom and Greenland. These phased-array, long-range radars are designed for ballistic missile detection and tracking. They play a critical role in the U.S. Missile Defense and Space Surveillance Network, with the capability to detect objects at distances of up to 3,000 miles.

UEWR systems operate in the 420–450 MHz frequency range and may feature multiple radar faces, each capable of transmitting at a peak power of 582.4 kW. Based on data from the earlier Raytheon AN/FPS-115 model and assuming a maximum antenna gain of 38.6 dB, the resulting peak EIRP is approximately 4.22 gigawatts (GW), with an average EIRP of 1.05 megawatts (MW). The estimated peak field strength is 11.7 kV/m at 100 feet distance - about 16 times higher than the 730 V/m specified in the current standard. There are only three such sites in the U.S., all located in sparsely populated areas, so avoidance is straightforward. However, the required separation distance may be substantial for vehicles with low HIRF tolerance levels. Section 5 provides sample calculations for this and other similar radar systems.

- **High-frequency (HF) broadcast stations**

The FCC authorizes approximately 15 HF broadcast transmitters operating in the 5.950 to 26.1 MHz frequency range, with power levels up to 500 kW and antenna gains ranging from 12 to 22.5 dB. These stations are primarily located in rural areas, making them relatively easy to avoid. Due to their limited number, the overall impact on VTOL operations is expected to be minimal. HF transmitter data are provided in Appendix B.

- **Experimental transmitters**

Experimental transmitters may be searched using the FCC Office of Engineering and Technology’s Experimental Licensing System (ELS). Ground-based transmitters with power levels high enough to pose HIRF concerns are rare and typically not located in urban areas. One notable example is Alaska’s High-Frequency Active Auroral Research Program (HAARP), which can transmit up to 3.63 GW average ERP in the HF band. The calculated vehicle stand-off distance is approximately 2.1 km for the current standard of 200 V/m, or 8.4 km for the 50 V/m tolerance level recommended in Section 4. Due to its remote location, HAARP is easily avoided. It is also worth noting that experimental transmitters were excluded from consideration in the original definition of HIRF environments.

- **Mobile/transportable ATC radars**

These systems are intended for temporary use during emergencies such as wildfires and tsunamis. In Japan, a transportable backup air traffic control (ATC) radar can transmit up to 500 kW peak power. With an antenna gain of 34 dB, this results in an EIRP of approximately 1.26 GW. Coordination with disaster management agencies is recommended to ensure appropriate avoidance measures.

- **Vessel Traffic Service and Coastal Surveillance Radar**

Vessel Traffic Service (VTS) systems are implemented in numerous ports worldwide to enhance maritime safety and operational efficiency. In the United States, 12 VTS locations are managed by the U.S. Coast Guard. While a comprehensive list of all global ports equipped with VTS radar is not readily available, several major ports are known for having advanced VTS installations. Examples include:

  - Port of Los Angeles / Long Beach (USA), with four radar sites
  - Port of London (United Kingdom), with 16 radars
  - Port of Singapore, with 19 radars
  - Port of Rotterdam (Netherlands), with 29 radars
  - Port of Hong Kong, with 14 radars

A VTS radar model may also function as a coastal surveillance radar (CSR). Typical radars operate in the X-band (9.0–9.5 GHz) or the S-band (2.9–3.1 GHz), with peak power levels ranging from 50 to 350 watts, a duty factor of 10-20%, and an antenna gain of 32-34 dB. This results in a maximum EIRP of 879 kW and a peak field strength of 168 V/m at the standard 100-foot distance. These transmitters are unlikely to pose a risk to an air vehicle with at least a 170 V/m peak field tolerance. Additionally, a W-band VTS radar operating at 77 GHz exists, though this frequency is beyond the scope of this study.

- **Transmitters on mobile platforms**

It is important to note that mobile transmitters were excluded from consideration when defining the original HIRF environments. Transmitters and radars on mobile platforms, such as ships and aircraft, may or may not pose a risk. For example, a radar with an EIRP equal to or lower than that of a CSR (as described above) may not present a hazard, provided the vehicle has sufficient tolerance. This tolerance level corresponds to at least 170 V/m (peak) at 100 feet, or 340 V/m (peak) at 50 feet.

In contrast, marine radars used on fishing vessels and commercial ships can have significantly higher peak power. Commercial models typically operate in the 3 GHz or 9.4 GHz bands, with output ranging from 250 W to 70 kW. The longest pulse-width settings in such systems are about 1 µs at a 650 Hz pulse repetition frequency (PRF) or 1.2 µs at a 510 Hz PRF. A 70-kW model with a 34 dB antenna gain can generate a peak field strength of approximately 2.38 kV/m at 100 feet.

Military shipborne radars are even more powerful and pose a substantial HIRF threat, making avoidance essential. With peak transmit powers ranging from 1 MW to 6 MW and antenna gains around 38 dB, these systems can produce field strengths at 100 feet ranging from 14.2 kV/m to 35 kV/m, far exceeding current HIRF standards.

- **Special Use Airspace (SUA) Emitters**

Emitters in SUA are not considered, as civil aircraft are prohibited from flying in such airspace, often due to military use. According to DOT/FAA/AR-98/69 [13], Table 22 lists approximately 50 emitter locations and models, though it is unclear whether these emitters are still in use.

Table 23 of the same report (below) also identified an additional 10 SUAs with high-power emitters and the corresponding stand-off radii for typical aircraft. One emitter had a stand-off radius of 45 nautical miles for standard aircraft. Many of these emitters have been updated since the report was published, and the data may still be relevant for avoidance considerations.

TABLE 23
PROPOSED SUA'S

Frequency Range	Emitter	Latitude and Longitude	SUA (Radius, Altitude)
400-700 MHz	FPQ-16	48.43.33N - 097.54.00W	5 nmi, 30,000 ft
400-700 MHz	FPT-5	42.37.10N - 071.29.30W	4 nmi, 23,000 ft
400-700 MHz	FPS-115	32.34.49N - 083.34.09W	1 nmi, 6,000 ft
400-700 MHz	FPS-115	30.58.42N - 100.33.09W	1 nmi, 6,000 ft
400-700 MHz	FPS-115	39.08.15N - 121.26.47W	1 nmi, 6,000 ft
1-2 GHz	FPS-108	52.43.37N - 174.05.49E	45 nmi, unlimited ft
1-2 GHz	LIL LONGRNGETRKRDR	42.37.02N - 071.29.29W	0.5 nmi, 3,000 ft
4-6 GHz	FPQ-14	26.58.00N - 080.06.00W	1.0 nmi, 6000 ft
4-6 GHz	FPQ-14	28.13.34N - 080.35.58W	1.0 nmi, 6000 ft
4-6 GHz	FPQ-14	21.34.30N - 158.16.30W	1.0 nmi, 6000 ft

Fig. 3-1a: ULS transmitter EIRPs and their power envelope to 2.5 GHz.

2.5 HIRF-Map Concept Findings and Discussions

The HIRF-map concept is technically viable for flight planning and may support reductions in vehicle tolerance levels. However, certain limitations should be noted. Additional observations and considerations are outlined below:

A. Databases

- The HIRF-map approach is technically feasible using regulatory fixed transmitter databases and other publicly available sources. The tools and methodology can be adapted to specific regions or countries as needed.

- Limited access to NTIA and FAA transmitter databases, particularly those related to airports, is recommended. This should be pursued through an approved liaison to address any associated security concerns. For now, military/government sites and airports should be excluded unless specific data are provided for the installation of interest.

- FCC databases do not provide comprehensive data on cellular wireless transmitters; therefore, vehicles should be inherently designed to tolerate emissions from these sources, making HIRF-map-based avoidance unnecessary for this class of transmitters.

- GPS location precision is improving in newer LMS database, with coordinates now often rounded to the nearest 0.1 degree - a notable improvement over older datasets. However, in the IBFS and ICFS databases, many entries still provide GPS coordinates for the overall facility rather than for individual antennas, which can reduce the accuracy of HIRF mapping.

B. Vehicle

- Although the HIRF-map approach can accommodate arbitrarily low vehicle tolerance levels, establishing a default baseline minimum is recommended to ensure practical usability. This is particularly important given the high number of low-power transmitters, such as those listed in ULS databases, and the lack of data for cellular/wireless base stations, unlicensed or unregulated devices, and handheld or portable transmitters.

C. Map

- The current HIRF-map tool displays HIRF zones based on individual frequency channels or carriers. However, it may be possible to configure the tool to account for the cumulative power of all co-located carriers.

- The demonstration used MATLAB's Web Map functionality. However, more advanced features may be achievable using other commercial mapping platforms.

D. Architecture

- This capability can be integrated into UAM, AAM, and UAS architectures as a Supplemental Data Service, like existing services for terrain, micro-weather, obstacles, and other operational factors. An example of a UAM system architecture is provided in [14]. It may also be incorporated into the Air Traffic Management system or directly into a vehicle's Flight Management System. Integration at the ATM level enables centralized management and coordinated avoidance across multiple vehicles, while integration at the vehicle level allows for autonomous, real-time decision-making tailored to each vehicle's HIRF tolerance.

3. Urban HIRF Environment and Field Tolerance Recommendation

This section presents the field environments in major urban areas and recommends vehicle tolerance levels. Subsections 3.1–3.4 focus on RF transmitters in New York City, a representative setting for VTOL, UAM, and other AAM operations. Transmitter EIRP is plotted against frequency using data from the ULS, CDBS, IBFS, and NOAA weather radar databases. Corresponding maximum field strengths are also plotted and compared with the current rotorcraft HIRF standard. Recommended minimum vehicle tolerance levels are provided by transmitter group. Subsection 3.5 summarizes the maximum observed field strengths and the associated tolerance recommendations.

Section 4 later expands the analysis to include eleven additional cities. Maximum field strengths in each location are reported and compared to both New York City and the HIRF-Average standard. Based on these comparisons and HIRF avoidance maps, revised tolerance recommendations are proposed.

It is important to note that the current rotorcraft HIRF standard assumes a minimum separation distance of 100 feet (approximately 30 meters) from transmitters for vehicles operating outside of airport environments ($R > 100$ m) [3]. This same assumption is applied throughout this paper when comparing calculated HIRF environments to the standard.

In New York City, transmitter EIRPs can reach up to 75 kW for ULS systems (e.g., 5G cellular), 1.64 MW for CDBS (digital television), and 1.26 GW for IBFS (satellite uplinks). NOAA weather radars, including NEXRAD and TDWR, can emit peak EIRPs of up to 25 gigawatts. At the standard evaluation distance of 100 feet, the resulting field strengths may reach 50 V/m from 5G wireless antennas, 230 V/m from digital TV transmitters, 6,376 V/m from satellite uplinks, and up to 28,382 V/m from weather radars. Several of these levels significantly exceed the HIRF environment standard for rotorcraft. The current rotorcraft HIRF standard is shown in Table 3-1 below.

Table 3-1: Rotorcraft Severe HIRF Environment (HIRF Environment III)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz(1)	150	150
100 kHz - 500 kHz	200	200
500 kHz - 2 MHz	200	200
2 MHz - 30 MHz	200	200
30 MHz - 70 MHz	200	200
70 MHz - 100 MHz	200	200
100 MHz - 200 MHz	200	200
200 MHz - 400 MHz	200	200
400 MHz - 700 MHz	730	200
700 MHz - 1 GHz	1400	240
1 GHz - 2 GHz	5000	250
2 GHz - 4 GHz	6000	490
4 GHz - 6 GHz	7200	400
6 GHz - 8 GHz	1100	170
8 GHz - 12 GHz	5000	330
12 GHz - 18 GHz	2000	330
18 GHz - 40 GHz	1000	420

3.1 ULS HIRF Environment and Recommended Vehicle Tolerance Level

Figs. 3-1a and 3-1b show the EIRP as a function of frequency, based on 24,667 ULS transmitter data records corresponding to 5,786 unique call signs in the New York City area. Each transmitter may be associated with multiple data records, each representing different combinations of frequency, power, modulation type, and other parameters. The study area spans approximately 40 km in latitude and 120 km in longitude, centered at the World Trade Center.

Fig. 3-1a displays data up to 2.5 GHz, while Fig. 3-1b extends the range to 30 GHz. Transmitter types include cellular, land-mobile radio, paging systems, microwave links, and others - each represented by a unique color and marker style. Due to limitations and outdated cellular emitter data in the ULS database, the cellular transmitter information used in these figures was supplemented with records from wireless providers in Hampton, Virginia, and Columbus, Ohio.

An EIRP envelope for the 17 HIRF sub-bands is also shown, with the maximum value reaching approximately 75 kilowatts for a 5G transmitter operating near 3.5 GHz. This envelope forms the basis for the corresponding field strength envelope at a 100-foot distance, as illustrated in Figs. 3-1c and 3-1d. The highest field strength observed is about 50 V/m from a 5G wireless transmitter, followed by approximately 44 V/m from a microwave link operating near 13 GHz. Below 2 GHz, land-mobile radios dominate the environment, but their peak field strengths remain below 20 V/m.

Table 3-2 summarizes the maximum EIRP and the corresponding field strengths for each of the 17 HIRF bands. These values were used to construct the power and field envelopes shown in Figs. 3-1(a–d).

It is observed that the field strength envelopes remain below 25 V/m for frequencies under 2 GHz and below 50 V/m for frequencies above 2 GHz, with some margin. Based on these findings, a reasonable recommendation for minimum vehicle tolerance levels is as follows:

- **ULS Tolerance Level Recommendation:**
  - 25 V/m below 2 GHz, and
  - 50 V/m above 2 GHz up to 40 GHz.

These levels enable a vehicle to tolerate all ULS transmitters without relying on the HIRF-map approach and serve as baseline tolerance levels across the frequency bands. Lower tolerance levels may be acceptable if a small number of transmitters are actively avoided. However, these values are not final; adjustments will be necessary to account for the higher power emissions from CDBS and IBFS transmitters.

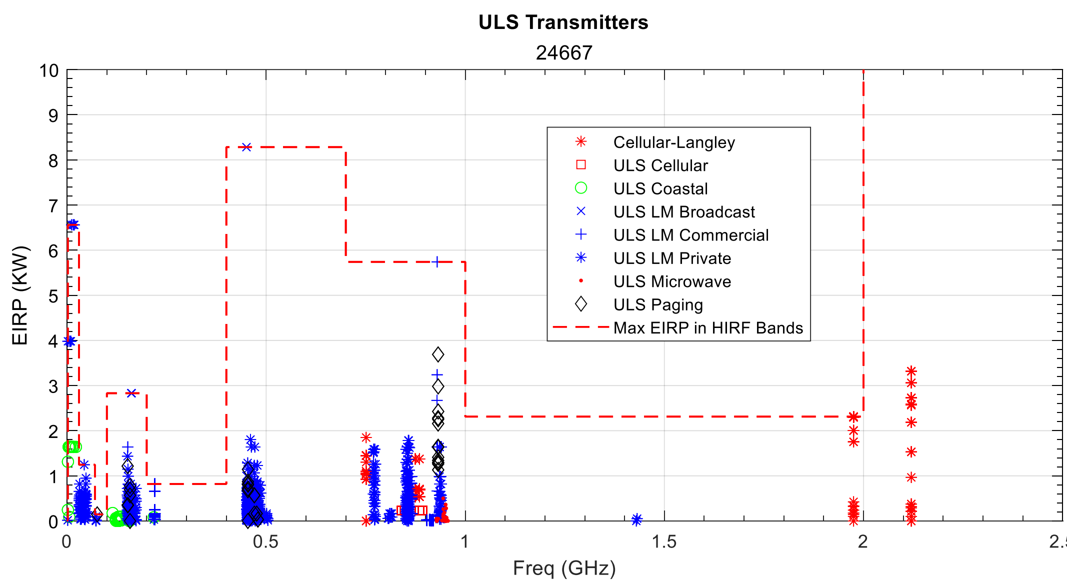


Fig. 3-1a: ULS transmitter EIRPs and their power envelope to 2.5 GHz.

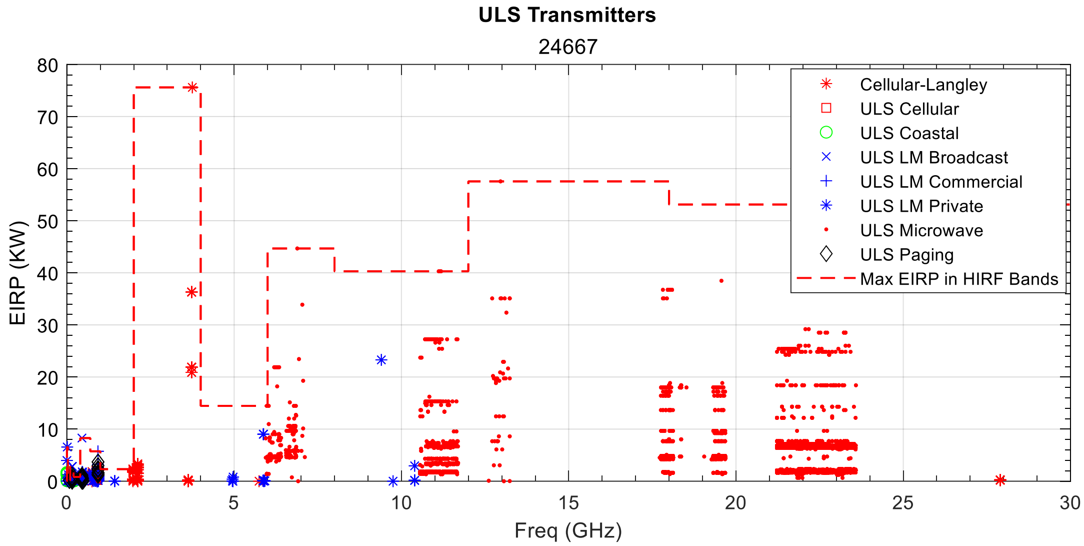


Fig. 3-1b: ULS transmitter EIRPs and their power envelope to 30 GHz.

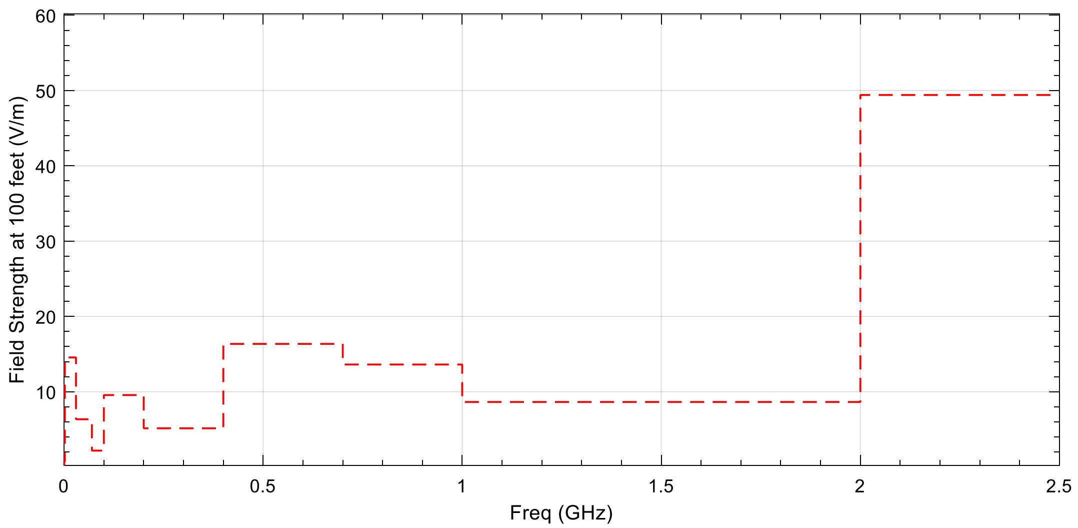


Fig. 3-1c: ULS 100-foot field strength envelope to 2.5 GHz.

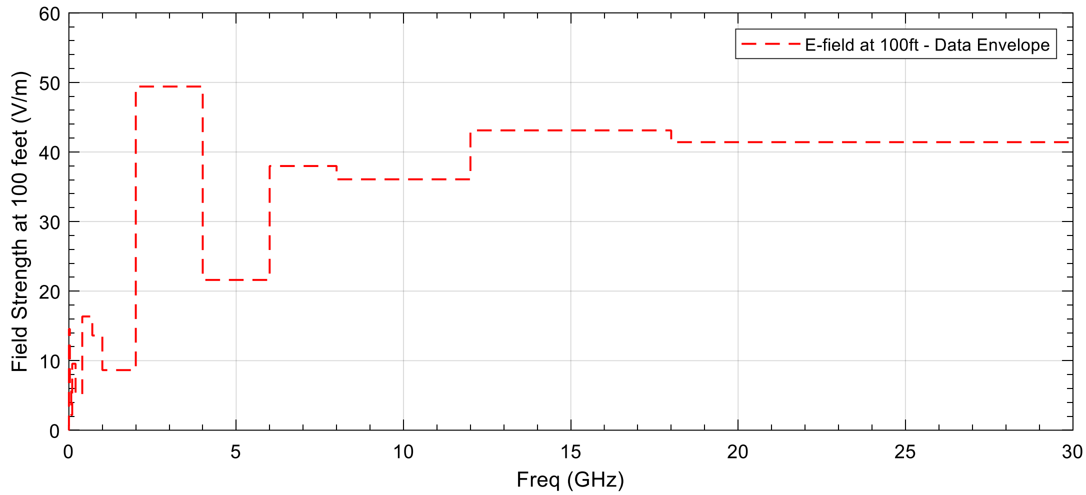


Fig. 3-1d: ULS 100-foot field strength envelope to 30 GHz.

Table 3-2: EIRP and field strength envelopes for ULS transmitters.

Bands	F1_GHz	F2_GHz	EIRP_kW	E_field
1	1e-05	0.0001	0	0
2	0.0001	0.0005	0	0
3	0.0005	0.002	0.016406	0.72786
4	0.002	0.03	6.56	14.555
5	0.03	0.07	1.2464	6.3442
6	0.07	0.1	0.14711	2.1795
7	0.1	0.2	2.8306	9.5607
8	0.2	0.4	0.82	5.1458
9	0.4	0.7	8.282	16.354
10	0.7	1	5.74	13.614
11	1	2	2.3121	8.6406
12	2	4	75.589	49.405
13	4	6	14.454	21.605
14	6	8	44.668	37.979
15	8	12	40.286	36.068
16	12	18	57.544	43.107
17	18	40	53.108	41.412

3.2 CDBS HIRF Environment and Recommended Vehicle Tolerance Level

Fig. 3-2a shows the EIRP values for AM (red), FM (blue), and TV (magenta) transmitters, along with their combined envelope. The maximum EIRPs observed are 50 kilowatts for AM, 65.6 kilowatts for FM, and 8.2 megawatts for analog TV transmitters. All transmitters in the CDBS database are included in the analysis, including legacy analog TV stations, which generally have higher power levels than their digital successors.

These EIRPs are converted to field strength at a 100-foot distance, with results shown in Figure 3-2b. The peak field strength recorded is 515 V/m, attributed to the 8.2-megawatt analog TV transmitter. This analysis is based on 1,011 FCC records corresponding to 138 unique call signs. The figure also includes the rotorcraft HIRF-Average standard (in green) for reference.

Although full-power analog TV broadcasting was banned in the U.S. in June 2009, some low-power and translator stations were permitted to continue until July 2024. Their data are included here to provide historical context and to compare with the HIRF standard, which predates the analog phase-out. The results show that analog TV transmitters could produce field strengths up to 515 V/m, significantly exceeding the 200 V/m threshold in the current standard. This exceedance indicates that the existing HIRF standard may not have adequately protected vehicles from the most powerful analog TV transmitters at the assumed 100-foot distance.

Figures 3-3a and 3-3b present the same CDBS data (2023) but exclude the high-power analog TV stations. Digital TV stations now dominate the 0.4–0.7 GHz range, with a maximum EIRP of 1.64 MW (equivalent to 1 MW ERP), which is the FCC's regulatory limit. The corresponding peak field strength is 230 V/m, significantly lower than the 515 V/m observed from legacy analog transmitters. Table 3-3 summarizes the maximum EIRP and field strength at 100 feet across the HIRF bands.

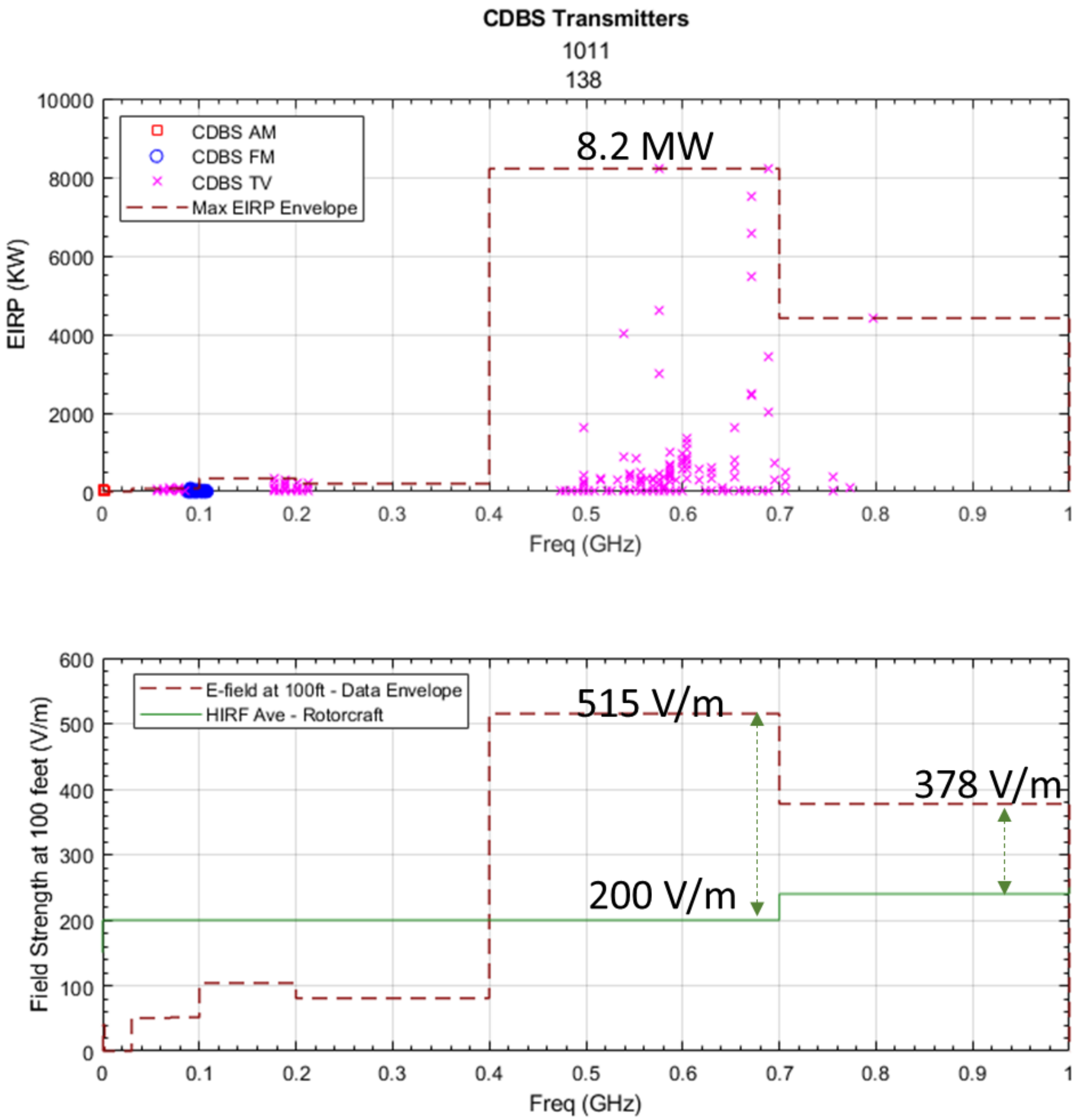
These figures also show a small number of transmitters between 0.7 and 1 GHz, producing up to 128 V/m at 100 feet. However, a separate search of the FCC's newer LMS database (as of December 2024) confirms there are no active digital TV transmitters in this band (TV channels 37 and above) for New York City and the eleven other cities in this study. This aligns with the FCC's ongoing spectrum repack initiative, which reallocates channels 38–51 for wireless broadband and mandates that full-power TV stations operate on channels 2–36 (up to 608 MHz).

As a result, the apparent transmitters in the 0.7–1 GHz band are likely outdated entries retained in the CDBS database and should be excluded from current analysis. Consequently, the actual field strength contribution from CDBS transmitters in this band is effectively zero. The initial recommended field tolerance levels, based on analysis for New York City, are as follows (subject to minor adjustment as data from other cities are incorporated).

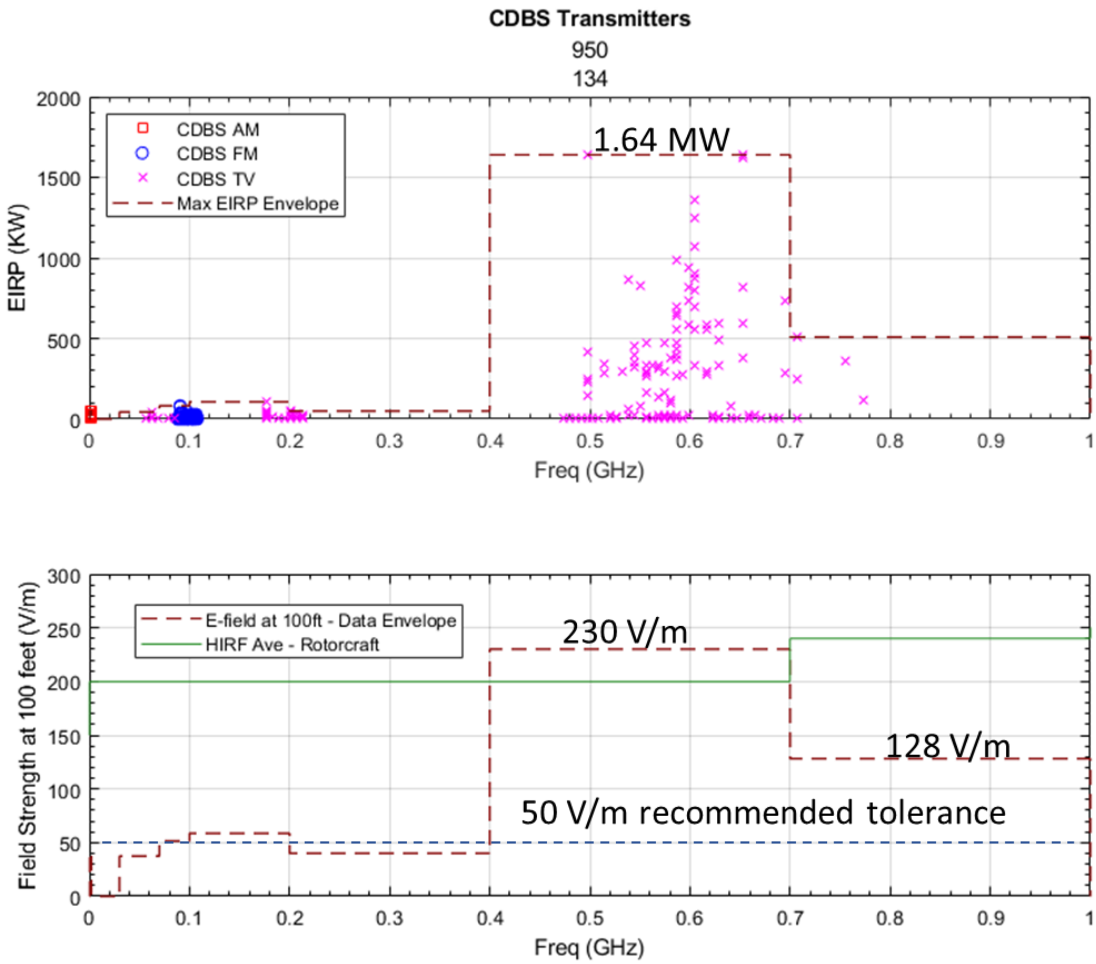
- **CDBS Tolerance Level Recommendation:**
  - 40 V/m (500 kHz – 2 MHz) (for AM)
  - 50 V/m (30 MHz – 0.7 GHz) (for FM and TV)

These levels are intentionally lower than the existing 200 V/m HIRF standard, which is desirable for reducing vehicle shielding requirements. They nearly provide sufficient protection for frequencies up to approximately 400 MHz. However, in the 400 MHz to 1 GHz range, these levels are insufficient to withstand the 100-foot field strengths from certain transmitters, thus requiring the use of the HIRF-Map approach to ensure safe navigation.

Figure 3-3c illustrates the HIRF-Map avoidance zones corresponding to a 50 V/m tolerance level, with TV-related HIRF zones shown in magenta. The figure shows that these zones are relatively few and geographically limited, making avoidance practical. Even if the tolerance level were halved, the resulting increase in avoidance zones would remain modest and would not significantly constrain the overall operational area.



Figs. 3-2a, 3-2b: CDBS transmitters field strength envelope and HIRF-Average standard. Include analog TV transmitters.



Figs. 3-3a., 3-3b. CDBS transmitters field strength envelope and HIRF-Average standard. Without analog TV transmitters. October 2023 data

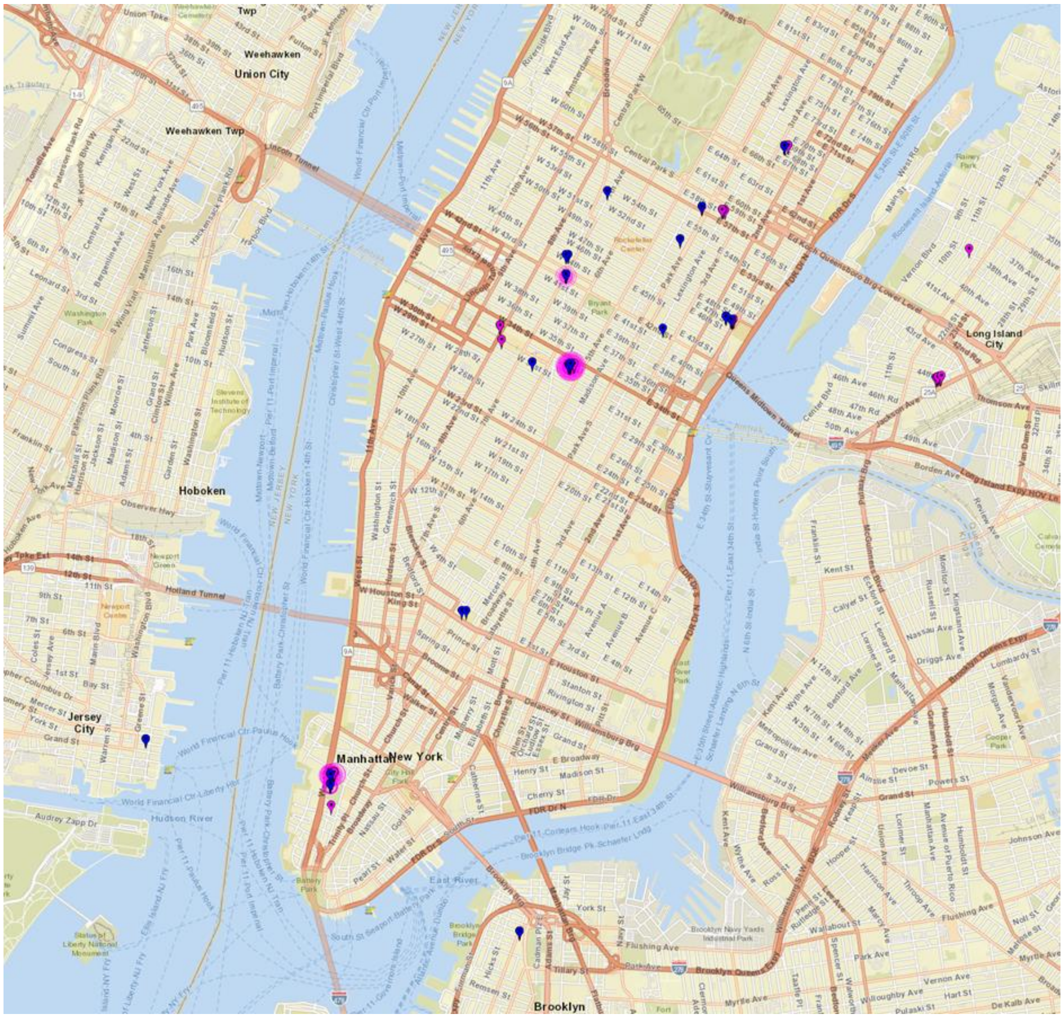


Fig. 3-3c: HIRF avoidance zones for CDBS transmitter. Vehicle tolerance set at 50 V/m.

Table 3-3: EIRP and electric field envelope for CDBS transmitters

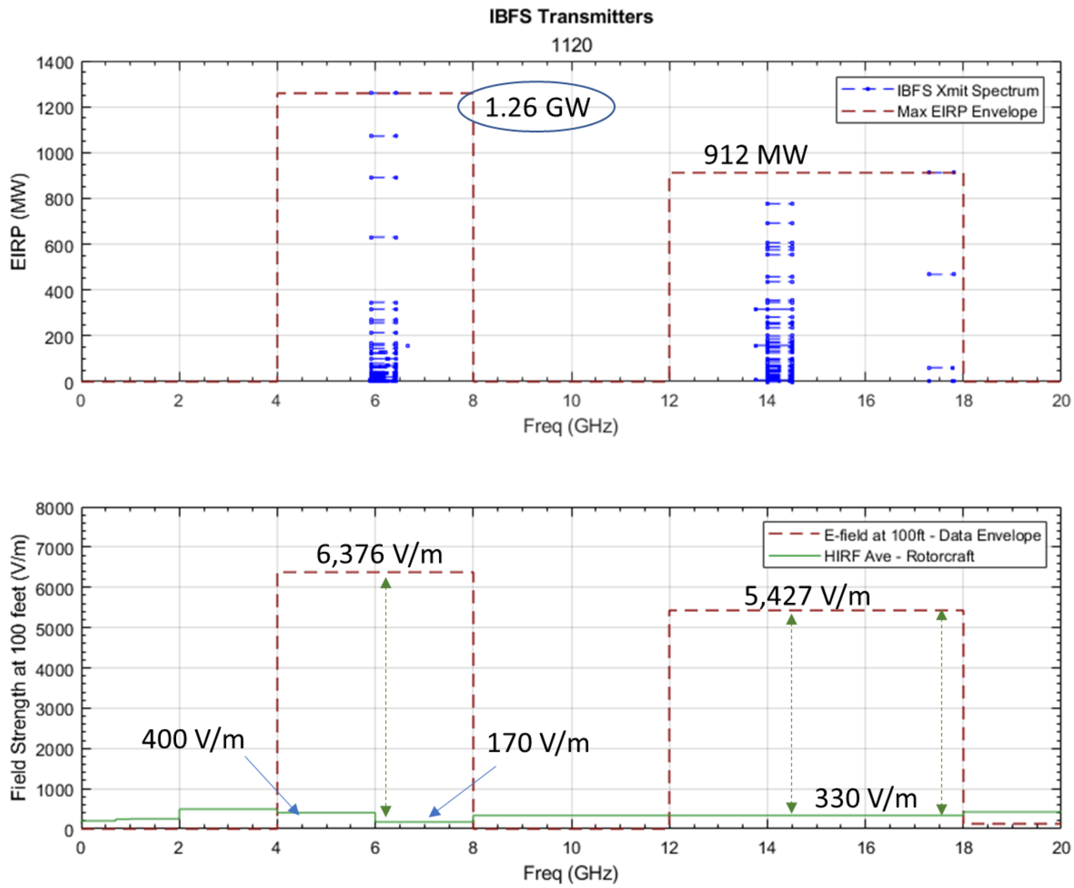
Bands	F1_GHz	F2_GHz	EIRP_kW	E_field
1	1e-05	0.0001	0	0
2	0.0001	0.0005	0	0
3	0.0005	0.002	50	40.182
4	0.002	0.03	0	0
5	0.03	0.07	43.46	37.462
6	0.07	0.1	82	51.458
7	0.1	0.2	106.6	58.671
8	0.2	0.4	49.527	39.991
9	0.4	0.7	1640	230.13
10	0.7	1	508.4	128.13

3.3 IBFS HIRF Environment and Recommended Vehicle Tolerance Level

Fig. 3-3a and 3-3b present the EIRP and 100-foot field strength envelopes for IBFS transmitters. EIRPs from individual carriers are plotted as shown. A transmitter maybe associated with several carriers within its transmission bandwidth. Due to the wide transmission bandwidths, EIRP data are depicted as line segments rather than individual markers as used for other transmitter types. Fig. 3-3a shows EIRP for individual carriers can reach up to 1.26 gigawatts.

Figure 3-3b illustrates that the corresponding field strengths can reach 6,376 V/m in the 4 - 8 GHz HIRF band and 5,426 V/m in the 12 - 18 GHz band. For comparison, the rotorcraft HIRF-Average standard, shown in green, is capped at 400 V/m, far below the IBFS field environment. This stark contrast underscores the inadequacy of the current standard against high-power satellite uplinks.

The analysis draws on 1,120 data records linked to 121 unique call signs. The detailed EIRP and field strength envelope data are summarized in Table 3-4.



Figs. 3-3a and 3-3b: IBFS transmitters EIRP envelope, field strength envelope, and HIRF-Average standard.

Table 3-4: EIRP and electric field strength envelope for IBFS transmitters

Bands	F1_GHz	F2_GHz	EIRP_kW	E_field
1	1e-05	0.0001	0	0
2	0.0001	0.0005	0	0
3	0.0005	0.002	0	0
4	0.002	0.03	0	0
5	0.03	0.07	0	0
6	0.07	0.1	0	0
7	0.1	0.2	0	0
8	0.2	0.4	0	0
9	0.4	0.7	0	0
10	0.7	1	0	0
11	1	2	0	0
12	2	4	0	0
13	4	6	1.2589e+06	6376
14	6	8	1.2589e+06	6376
15	8	12	0	0
16	12	18	9.1201e+05	5426.8
17	18	40	501.19	127.22

- **IBFS Tolerance Level Recommendation (Based on NY City Data):**

Using the HIRF-map approach in combination with a high vehicle tolerance level is critical when addressing IBFS sources. A low tolerance threshold would generate extensive avoidance zones, severely limiting the vehicle's available operational airspace.

Figure 3-3c illustrates a comparison of HIRF avoidance zones for tolerance levels of 250 V/m and 500 V/m. These levels yield manageable avoidance zone sizes, preserving substantial operational space for the vehicle. Although both levels are significantly lower than the peak field strengths listed in Table 3-4, the 500 V/m level exceeds the current rotorcraft HIRF-Average standard.

Based on IBFS transmitter conditions in New York City, the initially recommended field tolerance levels are as follows:

  - 250 – 500 V/m (4 – 18 GHz)

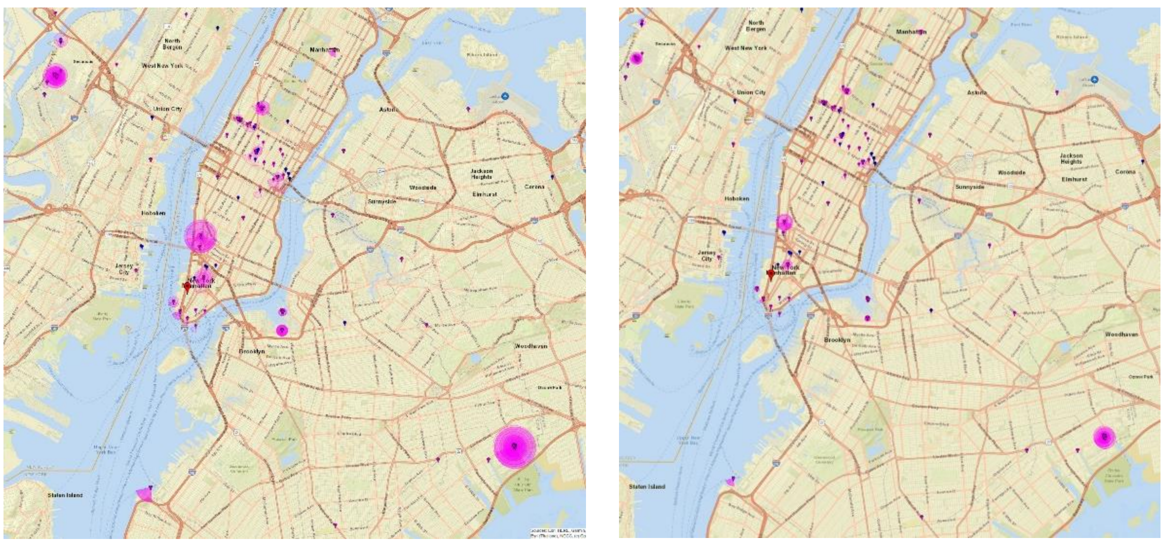


Fig. 3-3c: IBFS HIRF avoidance zones for 250 V/m (left) and 500 V/m (right).

Despite the reported severity of the IBFS transmitter environments, the reported figures may still underestimate the actual conditions. The 1.26 GW EIRP listed in Table 3-4 represents only one of twelve carriers within the 500 MHz licensed bandwidth of a single antenna. Fig. 3-4 below presents data from the FCC license, detailing all twelve carriers. Notably, two of these carriers each have an EIRP of 91 dBW, which is equivalent to 1.26 GW. The total EIRP could be much higher.

B) Particulars of Operations

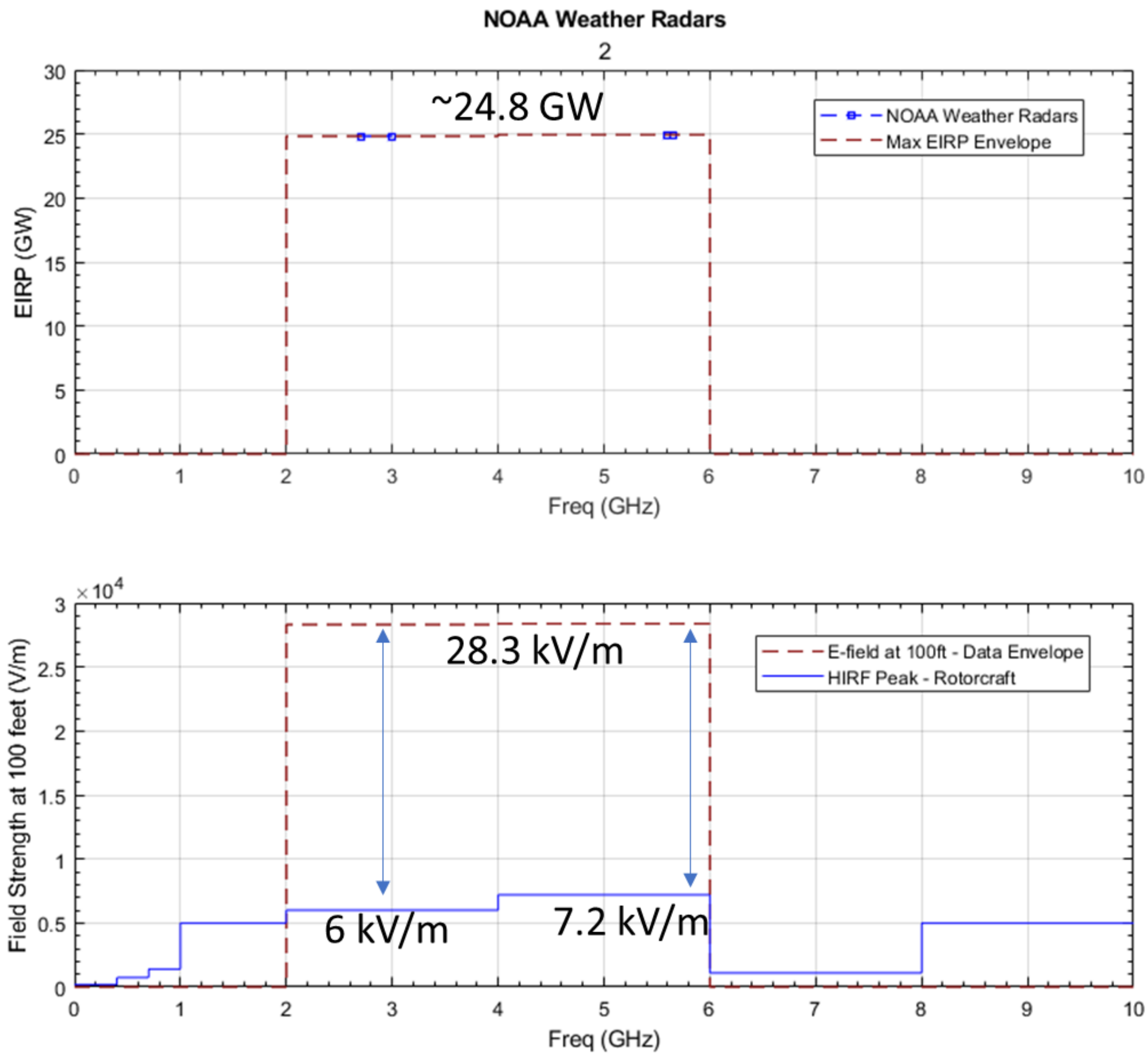
The General Provision 1010 applies to all receiving frequency bands.
The General Provision 1900 applies to all transmitting frequency bands.
For the text of these provisions, refer to Section H.

# Frequency	Polarization	Emission	Tx/Rx Mode	Max EIRP /Carrier	Max EIRP Density	Asso Ant
1) 5925.0000 - 6425.0000	H,V	2M50F9D	T	78.40	51.40	1
2) 5925.0000 - 6425.0000	H,V	36M0F9W	T	91.00	51.40	1
3) 5925.0000 - 6425.0000	H,V	36M0G7W	T	91.00	51.40	1
4) 5925.0000 - 6425.0000	H,V	10M0G7W	T	85.40	51.40	1
5) 5925.0000 - 6425.0000	H,V	7M40G7W	T	84.10	51.40	1
6) 5925.0000 - 6425.0000	H,V	1M34G7W	T	76.50	51.40	1
7) 5925.0000 - 6425.0000	H,V	500KG7W	T	72.40	51.40	1
8) 5925.0000 - 6425.0000	H,V	250KG7W	T	69.40	51.40	1
9) 5925.0000 - 6425.0000	H,V	48K0G7W	T	62.20	51.40	1
10) 5925.0000 - 6425.0000	H,V	400KF9W	T	71.40	51.40	1
11) 5925.0000 - 6425.0000	H,V	200KF9W	T	68.40	51.40	1
12) 5925.0000 - 6425.0000	H,V	50K0F9W	T	62.40	51.40	1

Fig. 3-4: FCC license data show EIRP data for each of the twelve carriers. The highest power carriers are highlighted.

3.4 NOAA Weather Radars HIRF Environment

Fig. 3-5a shows the EIRPs for both TDWR and NEXRAD transmitters, with peak values reaching 24.83 gigawatts. The corresponding field strength at a 100-foot distance is 28.4 kV/m, as shown in Fig. 3-5b. This field strength far exceeds the rotorcraft HIRF Peak standard limits of 6 kV/m and 7.2 kV/m in the 2–6 GHz range, underscoring the inadequacy of the current standard. Table 3-5 summarizes the calculation results.



Figs. 3-5a and 3-5b: EIRP and field strength envelopes for NOAA weather radars

Table 3-5: EIRP and electric field strength envelope for IBFS transmitters

Bands	F1_GHz	F2_GHz	EIRP_kW	E_field
1	1e-05	0.0001	0	0
2	0.0001	0.0005	0	0
3	0.0005	0.002	0	0
4	0.002	0.03	0	0
5	0.03	0.07	0	0
6	0.07	0.1	0	0
7	0.1	0.2	0	0
8	0.2	0.4	0	0
9	0.4	0.7	0	0
10	0.7	1	0	0
11	1	2	0	0
12	2	4	2.4831e+07	28317
13	4	6	2.4946e+07	28382
14	6	8	0	0
15	8	12	0	0
16	12	18	0	0
17	18	40	0	0

- **NOAA Weather Radar Tolerance Level Recommendation:**

Although the current standards of 6,000 V/m and 7,200 V/m are inadequate for protecting against NOAA weather radars, an initial recommended tolerance level of only 1,000 V/m is proposed. This 1,000 V/m threshold corresponds to an 866-meter stand-off distance. The lower tolerance level is considered acceptable because these radars are typically located outside densely populated urban areas, providing sufficient airspace for vehicle navigation. Additionally, there are only about 200 such transmitters across the U.S. Figure 3-5c illustrates the locations of two radar sites near New York City, with the 1,000 V/m avoidance zones highlighted in blue.

Some NEXRAD stations are located near airports, as illustrated in Fig. 2-7, with additional examples provided in Appendix C. In such cases, the tolerance level may be adjusted upward to reduce the size of avoidance zones when VTOL operations are required in these areas. For example, adopting a 2,000 V/m tolerance can reduce the size of the avoidance zone by half. Thus, the recommended tolerances are:

  - 2000 V/m, 2-4 GHz, Peak (for NEXRAD)
  - 1000 V/m, 4-6 GHz, Peak (for TDWR)

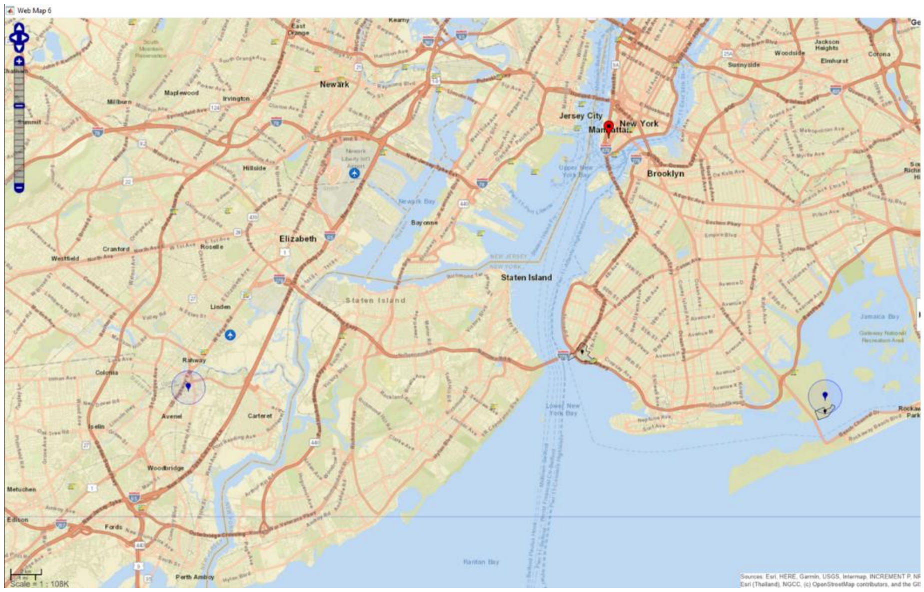


Fig. 3-5c: NOAA weather radars avoidance zones for a 1,000 V/m tolerance level.

3.5 Summary of Recommended Tolerance Levels for New York City

Table 3-6 summarizes the HIRF environments and the recommended minimum tolerance levels for ULS, CDBS, LMS, and IBFS transmitters. The “Maximum Field Environments” columns report the highest recorded field values from each respective database across the HIRF bands. In the CDBS column, values between 70 MHz and 1 GHz are crossed out, as they likely originate from legacy analog TV transmitters, which are now obsolete. Updated values from newer digital transmitters - listed under the LMS-TV column - should be used instead, as they are consistently lower than their analog predecessors. The “Composite” column represents the maximum field values drawn from the four primary transmitter categories.

The “Combined Tolerance” column reflects the highest of the recommended minimum tolerance levels. For comparison, the rotorcraft HIRF-Average standard is provided in column 3. Generally, the proposed tolerance levels are significantly lower than the current standard up to 4 GHz, supporting the objective of reducing HIRF-related compliance costs. Above 4 GHz, the recommended levels are comparable to the standard. However, the HIRF-map approach offers a more effective means of managing high-power transmitters than relying solely on static tolerance levels. Section 4 will examine additional major urban areas, where further adjustments to the recommended levels may be necessary.

Table 3-6: New York City HIRF Environments and Recommended Vehicle Tolerance Levels

HIRF Band	Freq. Range	HIRF Standard	Max Field Environments					Recommended Min. Tolerance				Combined Tolerance
			ULS	CDBS	LMS - TV	IBFS	Composite	ULS	CDBS	LMS - TV	IBFS	
1	10 kHz - 100 kHz	150						25				25
2	100 kHz - 500 kHz	200						25				25
3	500 kHz - 2 MHz	200	1	40			40	25	40			40
4	2 MHz - 30 MHz	200	15				15	25				25
5	30 MHz -70 MHz	200	6	50			50	25	50			50
6	70 MHz - 100 MHz	200	2	~~52~~	19		19	25	~~52~~	25		25
7	100 MHz -200 MHz	200	10	~~104~~	42		42	25	~~104~~	50		50
8	200 MHz - 400 MHz	200	5	~~81~~	42		42	25	~~81~~	50		50
9	400 MHz -700 MHz	200	16	~~515~~	175		175	25	~~515~~	50		50
10	700 MHz - 1 GHz	240	14	~~378~~			14	25	~~378~~			25
11	1 GHz - 2 GHz	250	9				9	25				25
12	2 GHz - 4 GHz	490	49				49	50				50
13	4 GHz - 6 GHz	400	22			6376	6376	50			250-500	250-500
14	6 GHz - 8 GHz	170	38			6376	6376	50			250-500	250-500
15	8 GHz - 12 GHz	330	36				36	50				50
16	12 GHz - 18 GHz	330	43			5427	5427	50			250-500	250-500
17	18 GHz - 40 GHz	420	41			127	127	50			250	250

4 Twelve-Cities HIRF Field Environments and HIRF Recommendation

In addition to New York City, similar analyses were conducted for eleven other U.S. cities: Chicago, San Francisco, Los Angeles, Dallas, Houston, Atlanta, Miami, Boston, Seattle, Phoenix, and Denver. This section summarizes the maximum field environments for all twelve cities.

New York City's recommended threshold serves as the baseline for determining suitable thresholds across all twelve cities. Initially, the baseline thresholds are applied in calculating the HIRF-maps for each city. A subsequent assessment ensures that these thresholds are appropriate and do not result in overcrowding of the airspace. The tolerance levels for ULS, CDBS, and IBFS systems are individually adjusted, with the maximum value in each HIRF band being used as the combined tolerance.

4.1 ULS

Table 4-1 compares the worst-case field strength envelopes for ULS transmitters across 12 major U.S. cities. Each column represents the worst-case environment for each city, based on approximately 5,600 to 97,600 FCC data records.

It was observed that nearly all data points fall below 25 V/m for frequencies under 2 GHz and below 50 V/m for frequencies above 2 GHz, consistent with the ULS data for New York City. However, there are some outliers. Fewer than 10 data points exhibit significantly higher power and field levels compared to similar services. For instance, a value of 2,278 V/m for Seattle/Band 15 corresponds to an EIRP of 160 MW at 9.735 GHz for the Land Mobile Radio service. This power level and frequency greatly exceed those of other Land Mobile Radio transmitters operating below 1 GHz, which typically have an EIRP of 8 kW or less. This data point, along with several others deemed similarly unreliable, has been crossed out in the table.

Several data points in the table are boxed, indicating transmitters with significantly higher power levels than their peers in similar services but which cannot be discounted at this time. For example, a value of 555 V/m for Seattle/Band 14 (6-8 GHz) corresponds to a microwave transmitter with an EIRP of 9.55 MW at approximately 6.9 GHz, more than 100 times higher than the next highest-power microwave transmitters. This data point is retained for further research. It is worth noting that these points overlap with IBFS transmitters in frequency. The higher tolerance required to address these high-power IBFS sources mitigates much of the concern.

Nevertheless, the recommended thresholds remain valid, as they exceed almost all ULS transmitter field strengths with very few exceptions. These exceptions can be addressed using the HIRF-map approach.

Table 4-1: Maximum ULS Field Envelopes for 12 Cities

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	**10 kHz - 100 kHz**	**150**													**0**	**25**
2	**100 kHz - 500 kHz**	**200**					1				13	1			**13**	**25**
3	**500 kHz - 2 MHz**	**200**	1	2	1	1	2	1	1	1	13	1	1	1	**13**	**25**
4	**2 MHz - 30 MHz**	**200**	15		18	7	13	7	7	7	7	18	1	10	**18**	**25**
5	**30 MHz -70 MHz**	**200**	6	4	4	5	5	4	4	4	5	4	5	4	**6**	**25**
6	**70 MHz - 100 MHz**	**200**	2	2	2	4	4	4	3	1	2	2	2	3	**4**	**25**
7	**100 MHz -200 MHz**	**200**	10	7	6	9	10	10	8	10	8	7	6	7	**10**	**25**
8	**200 MHz - 400 MHz**	**200**	5	5	5	4	4	5	4	5	3	5	2	1	**5**	**25**
9	**400 MHz -700 MHz**	**200**	16	7	14	14	10	36	7	8	8	17	8	10	**36**	**50**
10	**700 MHz - 1 GHz**	**240**	14	14	11	14	13	17	48	13	14	14	14	17	**48**	**50**
11	**1 GHz - 2 GHz**	**250**	9	9	9	9	9	9	9	9	9	9	9	9	**9**	**25**
12	**2 GHz - 4 GHz**	**490**	49	49	49	49	49	49	49	49	49	49	49	49	**49**	**50**
13	**4 GHz - 6 GHz**	**400**	22	20	16	27	115	~~788~~	16	17	0	16	38	32	**115**	**50**
14	**6 GHz - 8 GHz**	**170**	38	25	33	34	40	51	27	46	24	555	45	44	**555**	**50**
15	**8 GHz - 12 GHz**	**330**	36	38	~~161~~	52	30	~~738~~	30	~~1598~~	36	~~2278~~	75	48	**75**	**50**
16	**12 GHz - 18 GHz**	**330**	43	34	41	51	36	34	36	34	160	34	37	40	**160**	**50**
17	**18 GHz - 40 GHz**	**420**	41	40	44	46	29	24	24	24	35	35	41	36	**46**	**50**
# Records			**24,667**	**8,834**	**7,651**	**97,640**	**12,227**	**12,311**	**7,603**	**5,662**	**9,227**	**17,151**	**34,316**	**9,196**	**246,485**	

Notes:

- Boxed values are larger than the typical maximum.
- Crossed-out values are outliers and appear to be unreliable.
- Shaded boxes may require HIRF-Map approach to avoid.

- **Tolerance Level Recommendation:**

  For ULS transmitters, the recommended tolerances are consistent with those for New York City: 25 V/m for frequencies below 2 GHz and 50 V/m for frequencies above 2 GHz, as shown in the last column.

4.2 CDBS

Table 4-2 summarizes the field envelopes for CDBS transmitters across the 12 cities. The maximum field level can reach up to 515 V/m, which exceeds the 200 V/m HIRF standard for frequencies between 400 MHz and 1 GHz. The number of data records considered for each city ranges from 189 to 649. It is noted that data in this table exclude older analog TV transmitters which are obsolete and have higher transmit power than newer digital stations.

Table 4-2: Maximum CDBS Field Envelopes for 12 Cities

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150														
2	100 kHz - 500 kHz	200														
3	500 kHz - 2 MHz	200	40	18	38	40	40	18	40	40	40	40	40	20	40	40
4	2 MHz - 30 MHz	200														
5	30 MHz -70 MHz	200	37	13	13	13	13	13	13	13	13	2	2	2	37	50
6	70 MHz - 100 MHz	200	52	51	115	178	73	73	73	47	72	73	73	32	178	50
7	100 MHz -200 MHz	200	59	50	81	65	73	73	73	21	36	78	73	69	81	50
8	200 MHz - 400 MHz	200	40	39	82	0	34	0	12	0	0	92	46	0	92	50
9	400 MHz -700 MHz	200	230	230	230	230	230	56	230	28	230	230	230	75	230	50
10	700 MHz - 1 GHz	240	128	102	43	117	28	29	0	0	0	44	152	122	152	50
11	1 GHz - 2 GHz	250														
12	2 GHz - 4 GHz	490														
13	4 GHz - 6 GHz	400														
14	6 GHz - 8 GHz	170														
15	8 GHz - 12 GHz	330														
16	12 GHz - 18 GHz	330														
17	18 GHz - 40 GHz	420														

- **Tolerance Level Recommendation:**

  Considering CDBS transmitters in other cities and IBFS transmitters in bands 4 and 5, the recommended tolerance based on New York City has been revised, as shown in the last column of the table above. HIRF-map calculations for the 12 cities confirm that the levels do not result in overcrowded the airspace. The shaded boxes indicate frequencies where the HIRF-map approach should be used due to transmitters with field strengths exceeding the tolerance levels.

4.3 LMS-TV

Table 4-3 presents the maximum field environments from LMS TV transmitters across twelve cities. The data were obtained through a manual query of FCC records for the selected cities and represent the most current information available. Notably, HIRF Band 10 has been vacated by TV licensees. Additionally, maximum FM values are also included, as they fall within the same HIRF bands as TV broadcasts. Shaded cells indicate that the minimum recommended threshold values are below the maximum field strength at 100 feet, suggesting that HIRF maps should be used to support avoidance in those cases.

For HIRF Band 9, the maximum field strength is 230 V/m. Based on the recommended tolerance level of 50 V/m, the corresponding avoidance zone has a radius of approximately 460 feet (140 meters). This is considered acceptable due to the limited number of high-power LMS transmitters, which results in a low density of HIRF avoidance zones in each of the twelve cities. Examples of LMS TV transmitters are provided in Appendix A for New York, Chicago, and San Francisco.

Table 4-3: Maximum LMS-TV Field Envelopes for 12 Cities.

HIRF Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max FM	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150															
2	100 kHz - 500 kHz	200															
3	500 kHz - 2 MHz	200															
4	2 MHz - 30 MHz	200															
5	30 MHz -70 MHz	200	19	13	13	43	13	13	13	13	42	42	0	13		43	50
6	70 MHz - 100 MHz	200	19	13	13	43	13	13	13	13	42	42	0	13	73	73	50
7	100 MHz -200 MHz	200	42	40	51	78	49	56	65	91	0	0	46	53	73	91	50
8	200 MHz - 400 MHz	200	42	40	51	78	49	56	65	91	0	0	46	53		91	50
9	400 MHz -700 MHz	200	175	230	230	230	230	230	230	230	230	230	230	230		230	50
10	700 MHz - 1 GHz	240															
11	1 GHz - 2 GHz	250															
12	2 GHz - 4 GHz	490															
13	4 GHz - 6 GHz	400															
14	6 GHz - 8 GHz	170															
15	8 GHz - 12 GHz	330															
16	12 GHz - 18 GHz	330															
17	18 GHz - 40 GHz	420															

4.4 IBFS

Table 4-4 summarizes the field envelopes for IBFS transmitters across the twelve cities. Compared to the data for New York City, additional high-power transmitters were identified in Bands 12, 15, and 17, while maximum field strengths in Bands 13 and 14 increased to 6,943 V/m.

It is important to note that the data point in Band 4 for Atlanta is considered unreliable due to the low frequency. At 30 MHz, it is inherently difficult to concentrate RF energy to achieve high field strengths. Additionally, the data for Bands 13 and 14 are identical because the transmitters' spectra span both bands, as was also observed in the New York City data.

These field levels significantly exceed the 170–490 V/m range specified in the HIRF standard. Since increasing the standard average field limit to nearly 7,000 V/m is impractical, the HIRF-map approach proposed in this paper offers a practical and effective alternative.

Table 4-4: Maximum IBFS Field Envelopes for 12 Cities

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150														
2	100 kHz - 500 kHz	200														
3	500 kHz - 2 MHz	200														
4	2 MHz - 30 MHz	200							~~4023~~					127	127	75
5	30 MHz -70 MHz	200												127	127	75
6	70 MHz - 100 MHz	200														
7	100 MHz -200 MHz	200							18						18	
8	200 MHz - 400 MHz	200														
9	400 MHz -700 MHz	200			7		7					7			7	
10	700 MHz - 1 GHz	240														
11	1 GHz - 2 GHz	250					1								1	
12	2 GHz - 4 GHz	490		288	5427	1108	39	0	31	715	136	71	0	80	5427	250
13	4 GHz - 6 GHz	400	6376	5683	6943	6600	4514	5748	5183	6832	4656	5427	4311	4949	6943	250-500
14	6 GHz - 8 GHz	170	6376	5683	6943	6600	4514	5748	5183	6832	4656	5427	4311	4949	6943	250-500
15	8 GHz - 12 GHz	330		1756		2783	2689		1011						2783	250
16	12 GHz - 18 GHz	330	5427	2848	5243	6303	5065	5748	6376	4949	3087	5065	4023	6676	6676	250-500
17	18 GHz - 40 GHz	420	127		2369	5365	5521	216	359			4672	675	2538	5521	250
# Records			1,120	1,215	1,865	2,751	1,369	1067	2,545	2,206	288	601	525	1,058	16,610	

- **Tolerance Level Recommendation:**

  The previous recommendation for New York City has been revised to account for transmitters in Bands 12, 15, and 17. In these bands, the recommended field strength level is set to 250 V/m, reflecting the lower density of high-power transmitters in urban areas, which provides greater flexibility for vehicle navigation. Shaded boxes indicate regions where the HIRF-map approach is required to ensure effective transmitter avoidance.

4.5 Combined Recommendation – 12 Cities

Table 4-5 summarizes the recommended tolerance levels. The combined tolerance threshold reflects the maximum values among the recommended thresholds for ULS, CDBS, LMS-TV, and IBFS systems. These levels are significantly lower than the HIRF-Average standard for frequencies up to 4 GHz, a key objective of this analysis. For frequencies above 4 GHz, the recommended levels are comparable to or slightly exceed the standard, which is necessary to account for high-power IBFS transmitters not addressed by the current standard.

It is important to note that the recommended thresholds are intended as guidance. Users may adjust these levels to strike a balance between minimizing avoidance areas (through higher tolerance) and reducing system costs (through lower tolerance). However, selecting a tolerance level below the baseline derived from ULS data may result in increased exposure to a much larger number of ULS transmitters.

Shaded boxes in Table 4-5 indicate where the HIRF-map avoidance approach is required. Different colors represent the source databases for the HIRF-map: gray for ULS, beige for CDBS, and green for IBFS. For Band 14, which requires data from both ULS and IBFS transmitters, the Combined Threshold column displays both gray and green shading.

Table 4-5: Combined Tolerance Recommendation

HIRF Band	Freq. Range	HIRF Standard	Max Field Environments					Recommended Min. Tolerance				Combined Tolerance
			ULS	CDBS	LMS	IBFS	Composite	ULS	CDBS	LMS	IBFS	
1	10 kHz - 100 kHz	150						25				25
2	100 kHz - 500 kHz	200	13				13	25				25
3	500 kHz - 2 MHz	200	13	40	40		40	25	40	40		40
4	2 MHz - 30 MHz	200	18			127	127	25			50	50
5	30 MHz -70 MHz	200	6	37	43	127	127	25	50	50	50	50
6	70 MHz - 100 MHz	200	4	178	73		178	25	50	50		50
7	100 MHz -200 MHz	200	10	81	91	18	91	25	50	50		50
8	200 MHz - 400 MHz	200	5	92	91		92	25	50	50		50
9	400 MHz -700 MHz	200	36	230	230	7	230	50	50	50		50
10	700 MHz - 1 GHz	240	48	152			152	50	50			50
11	1 GHz - 2 GHz	250	9			1	9	25				25
12	2 GHz - 4 GHz	490	49			5427	5427	50			250	250
13	4 GHz - 6 GHz	400	115			6943	6943	50			250-500	250-500
14	6 GHz - 8 GHz	170	555			6943	6943	50			250-500	250-500
15	8 GHz - 12 GHz	330	75			2783	2783	50			250	250
16	12 GHz - 18 GHz	330	160			6676	6676	50			250-500	250-500
17	18 GHz - 40 GHz	420	46			5521	5521	50			250	250

4.6 Operations in Airport and Government Facilities

Given the recommended minimum vehicle tolerance levels outlined in Section 4.5, it is of interest to determine the maximum safe transmitter power levels at airports and government facilities for four specified distances: 50 feet, 100 feet, 150 feet, and 300 feet. These distances correspond to those used in calculating HIRF environments in the current standard, as defined in SAE ARP 5583A. Ensuring that transmitter power remains below these limits at the specified distances would help maintain vehicle safety if operations are permitted.

Table 4-6 presents the safe maximum average transmit power levels at these distances. The "Comments" column identifies examples of airport transmitters operating within the HIRF bands. These values represent average power and field strength levels and are not applicable to pulsed systems such as radars.

Table 4-6: Safe Average Transmit Powers Given the Recommended Tolerance Levels

Freq. Range	HIRF Standard	Veh. Tolerance	Max Xmit EIRP (kW) - Ave				Comments
			at 50'	at 100'	150'	at 300'	
10 kHz - 100 kHz	150	25	4.8	19	44	174	
100 kHz - 500 kHz	200	25	4.8	19	44	174	
500 kHz - 2 MHz	200	40	12.4	50	111	446	
2 MHz - 30 MHz	200	50	19.4	77	174	697	HF Comm (long range)
30 MHz -70 MHz	200	50	19.4	77	174	697	
70 MHz - 100 MHz	200	50	19.4	77	174	697	
100 MHz -200 MHz	200	50	19.4	77	174	697	VHF Comm, VOR, ILS Localizer, ATIS (Automatic Terminal Information Service)
200 MHz - 400 MHz	200	50	19.4	77	174	697	ILS Glideslope
400 MHz -700 MHz	200	50	19.4	77	174	697	
700 MHz - 1 GHz	240	50	19.4	77	174	697	DME
1 GHz - 2 GHz	250	25	4.8	19	44	174	DME, ADSB, Satcom L-Band; Secondary SR, ARSR
2 GHz - 4 GHz	490	250	483.9	1,935	4,355	17,419	ASR, Weather Radar, SMR (Surface Movement Radar), Satcom L-band (1.5-2.5 GHz)
4 GHz - 6 GHz	400	250	483.9	1,935	4,355	17,419	
6 GHz - 8 GHz	170	250	483.9	1,935	4,355	17,419	
8 GHz - 12 GHz	330	250	483.9	1,935	4,355	17,419	Weather Radar
12 GHz - 18 GHz	330	250	483.9	1,935	4,355	17,419	Satcom Ku-Band
18 GHz - 40 GHz	420	250	483.9	1,935	4,355	17,419	Satcom, Ka-Band

5 HIRF Map and Tolerance Thresholds for Weather and Surveillance Radars

Fig. 5.1 illustrates the known locations of key civilian surveillance radars, including ARSR, CARSR, SSR, and JSS systems, as well as NOAA weather radar installations. Notably, the ARSR, CARSR, and JSS categories are not mutually exclusive - a single installation may serve multiple functions. Additionally, Secondary Surveillance Radars (SSRs) are often co-located with primary radar systems. As a result, there are approximately 130 unique avoidance zones, in addition to about 200 NOAA weather radar sites. Airport Surveillance Radars (ASRs) are excluded due to insufficient data.

The avoidance zones depicted in Fig. 5.1 are relatively few and widely dispersed. With appropriate vehicle tolerance thresholds and safe separation distances, the risk of High-Intensity Radiated Fields (HIRF) exposure is expected to be minimal. Even accounting for other potential sources, such as high-frequency (HF) radios, high-power experimental transmitters, and military radars, the overall emitter density remains low and is not anticipated to pose significant HIRF concerns.

Section 5.1 describes the methodology used to recommend peak tolerance thresholds, which are primarily based on civilian emitters, the focus of this study. For context, stand-off distances for several military emitters are also provided in Section 5.2 and are based on the recommended tolerance level. A summary of the recommended values for both peak and average tolerance are shown in Table 5.3. These recommendations may be revised in the future as additional data become available.

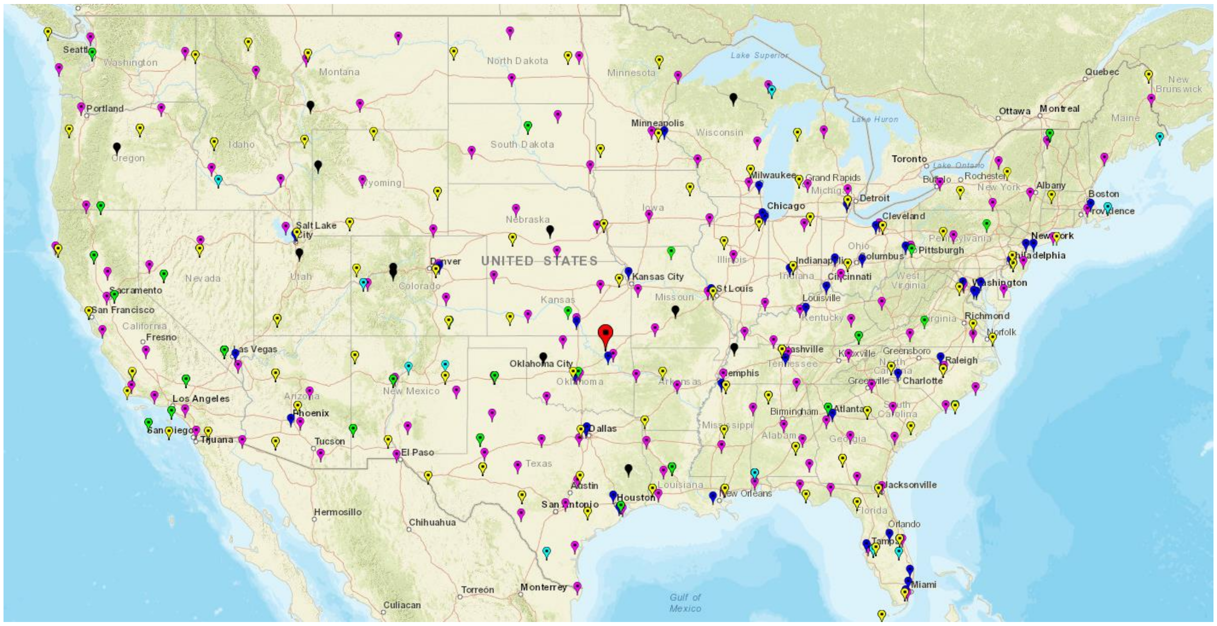


Fig. 5.1: Locations of ARSR (cyan), CARSR (green), SSR (black), and JSS (yellow) transmitters, along with 200 NOAA's NEXRAD and TDWR (magenta and blue). Note that many markers overlap due to shared or co-located systems. The large red marker indicates the map center.

5.1 Peak HIRF Tolerance Level Against Civilian Emitters

Table 5.1 outlines a framework for establishing tolerance thresholds for civilian radar sources, including those operated by the FAA. These systems include:

- SSR and ARSR (1–2 GHz band),
- ASR, Digital ASR (DASR), and NEXRAD (2–4 GHz band), and
- TDWR (4–6 GHz band).

The framework also considers marine radars and several other radar types. Transmitter technical data was sourced from Wikipedia, radartutorial.edu, equipment manufacturer websites, and other references. Where specific data were unavailable, reasonable assumptions about antenna gain were made.

Unlike dense urban environments, where transmitter populations are high, the avoidance zones associated with radar systems are generally more isolated.

Let:

- T_{urban} (V/m) be the average field tolerance previously selected for urban areas,
- T_{ave} (V/m) be the tolerance against average power from pulsed sources,
- T_{peak} (V/m) be the tolerance against peak power from pulsed sources.

Tolerance levels for each frequency band are determined using the following guidelines:

1. <u>Single tolerance level per band</u>: Assign one tolerance value per HIRF frequency band, based on the worst-case field strength within that band.

2. <u>Account for Both Peak and Average Power</u>: Both the peak and average field levels are considered as many radar systems exhibit relatively high average power due to high duty factor.

3. <u>Use Urban Tolerance as Baseline</u>:

    - Start by seting $T_{ave} = T_{urban}$
    - Determine T_{peak} such that the resulting HIRF radius is equivalent for both average and peak power.
    - If T_{peak} is higher than desirable, reduce it incrementally (resulting in increased HIRF radius) until an acceptable balance between HIRF radius and the peak field strength is achieved. In sensitive areas, such as airports where some VTOL operations are expected, large HIRF radii may not be acceptable.
    - Repeat this evaluation process for each relevant emitter.
    - In some cases, it may be necessary to increase T_{urban} to achieve a feasible HIRF radius based on average power. However, minimizing T_{urban} remains a high priority.

Table 5.1: Calculations of Thresholds Against Civilian Radar Emitters

HIRF Freq. Band	Service	Radar Model	Freq. (MHz)	Peak/Ave Power (kW)	Type	Pulsewidth (usec)	Ant. Gain (dBi)	EIRP (MW)	E_100' (Peak/Ave) (V/m)	HIRF Standard (V/m)	T_urban (V/m)	Input Tolerance (T_Peak/Ave)	HIRF Radius R (m) (Peak/Ave)	Notes
Band 11	SSR	Mode S	1030	2			35	6.3	452	5000		215	64.1	Defer to ARSR-4
1-2 GHz		ATCRBS		2			35	6.3	452	5000		215	64.1	
	ARSR/	ARSR-4	1215-1400	65	Solid-state	150	35	205.5	2,576	5000		215	365.2	Band driver
	CARSR	Ave:		3.5			35	11.1	598	250	25	50	364.4	Raise T_urban to 50 V/m
		CARSR	1215-1400	65	Solid-state		34	163.3	2,296	5000		215	325.5	
		Ave:								250	25	50		
		ARSR-3	1250-1350	5000	Tube	2	34	12,559.4	20,139	5000		~~215~~	~~2855.0~~	Obsolete?
		(Obsolete)		3.3			34	8.3	517	250	25	~~50~~	~~315.4~~	
	ASR/	ASR-9	2700-2900	1300	Tube	1	34	3,265.5	10,269	6000		2000	156.5	Selected to be band driver
Band 12	DASR	Ave:		1.5			34	3.8	349	490	250	250	42.5	due to use at large airports
2-4 GHz		ASR-11	2700-2900	25	Solid-state	1 & 80	34	62.8	1,424	6000		2000	21.7	Smaller airports &
		Ave:		2.1			34	5.3	413	490	250	250	50.3	military bases
		ASR-10SS	2700-2900	19.5	Solid-State	1 & 100	34	49.0	1,258	6000		2000	19.2	Outside US
		ASR-12	2700-2900	22	Solid-state		34	55.3	1,336	6000		2000	20.4	
	VTS, CSR	VTS, CSR	2.9-3.1 GHz	0.35	Solid-State		34	0.9	168	6000		2000	2.6	Port &
		Ave:		0.07		20% duty	34	0.2	75	490	250	250	9.2	Coastal surveillance
	Marine	Com. Shipping	3000	70			34	175.8	2,383	6000		2000	36.3	Commercial shipping
	Radar	Ave:		0.0428		1.2	34	0.1	59	490	250	250	7.2	marine radar
	Weather	NEXRAD	2700-3000	700	Tube	1.57, 4.7	45.5	24,836.9	28,320	6000		2000	431.6	Wx Increase field due to
	Radar	Ave:	2700-3000	1.3			45.5	46.1	1,220	490	250	250	148.8	poss. proximity to airport
Band 13		TDWR	5600-5650	250	Tube	1.1	50	25,000.0	28,413	7200		1000	866.0	
4-6 GHz		Ave:	5600-5650	0.55		1.1	50	55.0	1,333	400	250	250	162.5	
Band 15	VTS, CSR	VTS, CSR	9000-9500	0.35	Solid-State		34	0.9	168	5000		1000	5.1	Port surveillance
8-12 GHz		Ave:		0.07		20% duty	34	0.2	75	330	250	250	9.2	Coastal surveillance
	ASDE-X	X-band ASDE	9000-9200	0.075		100	37	0.4	110	5000		1000	3.4	9.3-9.5 GHz in Europe
		Ave:		0.03		~ 40% duty	37	0.2	70	330	250	250	8.5	Model Saab SMR SR-3
	LPAR	Low-power	9000-9600	0.1254		6-55 us	37	0.6	142	5000		1000	4.3	Skyler
		Phased Array		0.023			37	0.1	61	330	250	250	7.4	
	Airborne	Airborne	9500	4		10%	27.15	2.1	259	5000		1000	7.9	General Dynamics
		Ave:		0.4			27.15	0.2	82	330	250	250	10.0	X-band airborne radar
	Marine	Com. Shipping	9400	70			34	175.8	2,383	5000		1000	72.6	Commercial shipping
	Radar	Ave:		0.0428		1.2	34	0.1	59	330	250	250	7.2	marine radar
Band 16	ASDE-3	SMR	15700-16200	10			37	50.1	1,272	2000		1000	38.8	Obsolete?
12-18 GHz											250	250		
	ASDE-X	SMR	Ku band	3		40 ns	37	15.0	697	2000		1000	21.2	Est. gain
		Ave:		0.001			37	0.0	13		2000	250	1.6	Typical specs

Referring to Table 5.1, in Band 11 (1–2 GHz), the ARSR-4 is considered the worst-case emitter. Setting the average tolerance T_{ave} = T_{urban} (50 V/m) results in a HIRF radius of 364 meters. Note that T_{urban} was increased from the previously recommended 25 V/m to 50 V/m to reduce the HIRF radius. The peak tolerance T_{peak} is set to 215 V/m to match this radius. Increasing T_{peak} beyond this value does not reduce the HIRF radius further, as T_{ave} remains the limiting factor. Therefore, the only way to reduce the HIRF radius in this case is to increase T_{urban} beyond 50 V/m.

In Band 12 (2–4 GHz), the primary emitters are ASR-9 and NEXRAD. Using T_{ave} = T_{urban} = 250 V/m for ASR-11 and ASR-9 results in HIRF radii under 50.3 meters. However, matching this small radius for peak power would require an impractically high T_{peak} (approximately 7,000 V/m). Instead, setting T_{urban}= 1,000 V/m results in a HIRF radius of 313 meters from ASR-9 radars, which is considered acceptable for airport environments.

As previously recommended, a T_{peak} of 1,000 V/m for NEXRAD and TDWR systems results in a HIRF radius of approximately 866 meters, which is generally acceptable. However, there are about ten instances where a NEXRAD station is located directly on airport property, such as the example shown in Fig. 2-7 (Corpus Christi, TX) and Figs. C1–C7. This relatively large HIRF radius may affect VTOL operations in some cases.

Most airports with nearby NEXRAD stations tend to fall into the small hub or smaller categories. Smaller airports may use less powerful ASR radars, so the associated HIRF-radii may be smaller. In the scenario where a more powerful ASR-9 radar system is also present nearby, the combined avoidance areas would be larger; in such cases, increasing the T_{peak} to 2,000 V/m for Band 12 is recommended. Appendix C lists known airports with nearby NEXRAD or TDWR stations nearby.

For Band 13 (4–6 GHz), a T_{peak} =1,000 V/m is sufficient, as none of the TDWR stations operating in this band is located within an urban area or an airport that would restrict the avoidance zone size.

Band 15 (8–12 GHz) includes data for commercial marine radar, Vessel Traffic Service (VTS), Coastal Surveillance Radar (CSR), and Airport Surface Detection Equipment, Model X (ASDE-X). With commercial marine radar being the dominant emitter in this band, a T_{peak} of 1,000 V/m results in a HIRF radius of 72 meters for this radar. The HIRF radii are under 10 m for VTS, CSR, and ASDE-X, calculated based on T_{ave} of 250 V/m.

For Band 16 (12–18 GHz), a T_{peak} of 1,000 V/m is recommended. Assuming an antenna gain of 37 dB (subject to confirmation), the calculated HIRF radii are 39 meters for ASDE-3 and 21 meters for ASDE-X radars installed at airports.

5.2 HIRF Avoidance Against Military Emitters

Table 5.2 presents data for several military radars, with HIRF radii calculated based on the T_{urban} and T_{peak} values defined in Table 5.1. Results are shown for both peak and average power scenarios. Although some military radars produce very large avoidance radii, up to 9.3 km, these are considered acceptable due to the relatively sparse deployment of such systems.

Military radars are not used to establish tolerance thresholds, given the limited exposure expected for VTOL aircraft during normal operations. An exception is Band 9 (400–700 MHz), where no common civilian radars exist; in this case, a military system is used to recommend a peak threshold.

Table 5.2 shows that applying the above calculation method yields a T_{peak} of 225 V/m for the AN/FPQ-16 radar. This results in the same HIRF radius for both peak and average power. Since HIRF radius from T_{ave} is a limiting factor, increasing T_{peak} alone does not reduce the HIRF radius. While increasing both T_{ave} and T_{peak} can decrease the radius, doing so would require raising T_{urban}, which is generally less desirable.

Table 5.2: HIRF Calculations for Sample Military Radars

HIRF Freq. Band	Service	Radar Model	Freq. (MHz)	Peak/Ave Power (kW)	Type	Duty & Pulsewidth (usec)	Ant. Gain (dB)	EIRP (MW)	E_100' (Peak/Ave) (V/m)	HIRF Standard (V/m)	T_urban (V/m)	Input Tolerance (T_Peak/Ave)	HIRF Radius R (m) (Peak/Ave)	Notes
Band 9	UEWR	AN/FPS-132	420-450	582.4			38.6	4,219.1	11,672	730		100	3,557.7	3 locations in US
400-700 MHz		Ave:		145.6			38.6	1,054.8	5,836	200		50	3,557.7	
		AN/FPQ-16	420-450	14400			38.6	104,318.8	58,040	730		225	7,862.5	"PARCS"
400-700 MHz		Ave:		715			38.6	5,179.7	12,933	200		50	7,883.9	1 location
Band 11		AN/FPS-108	1175-1375	16000			38.6	115,909.8	61,179	6000		215	8,673.3	"Cobra Dane"
1-2 GHz		Ave:		1000			38.6	7,244.4	15,295	490		50	9,323.8	Alaska
		AN/FPS-117	1215-1400	20	solid-state	100 & 80	35	63.2	1,429	7200		215	202.6	"Seek Igloo"
		(estimated ant. gain)												NORAD
	Weather	AN/FMQ-19		???			35			7200		215		
Band 12	Tactical	AN/TPS-43	2900-3100	2800			35	8,854.4	16,909	7200		2000	257.7	Tactical Air Defense
2-4G		Ave:		6.7		6.5	35	21.2	827	400		250	100.8	
	Tactical	AN/TPS-75	2900-3100	2800			35	8,854.4	16,909	7200		2000	257.7	Tactical Air Defense
		Ave:		4.7			35	14.9	693	400		250	84.5	
	Surface	NTIA Specs	3100-3700	1000		0.80%	40	10,000.0	17,970	7200		2000	273.9	Land-based Surface Radar
	Land base	Ave:		8			40	80.0	1,607	400		250	196.0	Data from NTIA
	Surf+Air	NTIA Specs	3100-3700	640		2-32%	39	5,083.7	12,813	7200		2000	195.3	Land-based Surface + Air
	Land base	Ave:		204.8			39	1,626.8	7,248	400		250	883.7	Data from NTIA
	Airborne	NTIA Specs	3100-3700	1000		5%	40	10,000.0	17,970	7200		2000	273.9	Airborne radar
		Ave:		50			40	500.0	4,018	400		250	489.9	Data from NTIA
	Ship	NTIA Specs	3100-3500	6400		0.8-2%	42	101,433.2	57,232	7200		2000	872.2	Shipborne radar
		Ave:		128		6.4-51.2 us	42	2,028.7	8,094	400		250	986.8	NTIA, 3100-3300
	Ship	NTIA Specs	3500-3650	1000		0.28,0.67%	32	1,584.9	7,154	7200		2000	109.0	Shipborne radar
		Ave:		6.7		0.25,0.6 us	32	10.6	586	400		250	71.4	Data from NTIA
Band 13		AN/FPQ-14	5400-5900	2800			53.8	671,673.2	147,274	7200		1000	4,488.9	Air defense system
4-6 GHz		Ave:		4.8			53.8	1,151.4	6,098	400		250	743.4	NIKE
Band 15	PAR	AN/FPN-63(V)	9000-9160	80		0.2	34	201.0	2,547	5000		1000	77.6	
8-12 GHz		(estimated P_ave & ant gain)		0.052		0.2	34	0.1	65	330	250	250	7.9	

5.3 HIRF Tolerance Recommendation Summary

Table 5.3 summarizes the recommended peak and average tolerance thresholds, as derived from Section 4.5 and this Appendix. Note that underlined peak values are carried over from the average recommended thresholds in cases where no known radars operate within the respective bands. The recommended average threshold for Band 11 has been increased from 25 V/m (as stated in Section 4.5) to 50 V/m to account for higher radar average power, as discussed. Both the peak and average recommended thresholds remain below current standards, as intended.

Table 5.3: HIRF Peak and Average Field Tolerance Recommendation for VTOLs

HIRF Band	Freq. Range	Standard		Recommendation	
		Peak	Average	Peak	Average
1	10 kHz - 100 kHz	150	150	25	25
2	100 kHz - 500 kHz	200	200	25	25
3	500 kHz - 2 MHz	200	200	40	40
4	2 MHz - 30 MHz	200	200	50	50
5	30 MHz -70 MHz	200	200	50	50
6	70 MHz - 100 MHz	200	200	50	50
7	100 MHz -200 MHz	200	200	50	50
8	200 MHz - 400 MHz	200	200	50	50
9	400 MHz -700 MHz	730	200	225	50
10	700 MHz - 1 GHz	1400	240	50	50
11	1 GHz - 2 GHz	5000	250	215	50
12	2 GHz - 4 GHz	6000	490	2000	250
13	4 GHz - 6 GHz	7200	400	1000	250-500
14	6 GHz - 8 GHz	1100	170	250	250-500
15	8 GHz - 12 GHz	5000	330	1000	250
16	12 GHz - 18 GHz	2000	330	1000	250-500
17	18 GHz - 40 GHz	1000	420	1000	250

6 Conclusions

The HIRF-map concept appears to be a feasible solution for urban Advanced Air Mobility (AAM) operations. The minimum recommended vehicle tolerance levels are derived from regulatory databases of high-power transmitters across twelve major U.S. cities and known civilian radar sites. This approach enables significantly lower vehicle HIRF tolerance levels in certain frequency ranges compared to the current standard, while still providing avoidance maps for high-field environments that far exceed standard limits. Operations within airports and other government airspace should remain restricted unless additional transmitter data are available for the specific location of interest.

7 Acknowledgement

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Matlab Web Map and Google Maps were used in the figures. More information can be found in [10,15,16].

8 References

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16. Google Maps: http://map.google.com

Appendix A: LMS-TV data for New York, Chicago, and San Francisco

Examples of LMS-TV transmitter data for New York, Chicago, and San Francisco are listed below. The maximum power is 1000 KW (ERP). This 1000 KW maximum matches that of nine other cities. It is noted that the highest power transmitters have DTV as the service code. Stations with LPD and DCA service have lower transmit power levels.

Call	---KML maps--	Channel	Virtual Channel	Service	Status	ATSC 3 (Nextgen TV)?	City	State	Country	File Number	FacilityID	ERP	HAAT	Licensee/Permittee
W02CY-D	KML/Fill/Text	2	45	LPD	LIC	-	NEW YORK	NY	US	0000178220	130477	.5 kW	- m	HC2 STATION GROUP, INC.
WNWT-LD	KML/Fill/Text	3	18	LPD	LIC	-	NEW YORK	NY	US	0000074714	22797	6.96 kW	340.2 m	WJLP-TV LIMITED PARTNERSHIP
WNYZ-LD	KML/Fill/Text	6		LPD	STA	-	NEW YORK	NY	US	0000184381	56043	3. kW	- m	SOUND OF LONG ISLAND, INC.
WNYZ-LD	KML/Fill/Text	6		LPD	LIC	-	NEW YORK	NY	US	0000184380	56043	3. kW	- m	SOUND OF LONG ISLAND, INC.
WABC-TV	KML/Fill/Text	7	7	DTV	CP	-	NEW YORK	NY	US	BMPCDT-20080620AMV	1328	34. kW	506. m	WABC TELEVISION (NEW YORK), LLC
WABC-TV	KML/Fill/Text	7	7	DTV	LIC	-	NEW YORK	NY	US	0000227428	1328	34. kW	405. m	WABC TELEVISION (NEW YORK), LLC
WNYP-LD	KML/Fill/Text	10		LPD	CP	-	NEW YORK	NY	US	0000251507	130475	3. kW	- m	VENTURE TECHNOLOGIES GROUP LLC
WPIX	KML/Fill/Text	11	11	DTV	LIC	-	NEW YORK	NY	US	0000227437	73881	26. kW	405. m	MISSION BROADCASTING, INC.
WKOB-LD	KML/Fill/Text	13		LPD	LIC	-	NEW YORK	NY	US	0000198500	51441	3. kW	- m	HC2 STATION GROUP, INC.
WNMF-LD	KML/Fill/Text	17		LPD	STA	-	NEW YORK	NY	US	0000063470	74513	0.005 kW	- m	LOCAL MEDIA TV NEW YORK, LLC
WNMF-LD	KML/Fill/Text	17		LPD	STA	-	NEW YORK	NY	US	0000219533	74513	0.005 kW	- m	LOCAL MEDIA TV NEW YORK, LLC
WNMF-LD	KML/Fill/Text	17		LPD	LIC	-	NEW YORK	NY	US	BLDTL-20130325APT	74513	1. kW	- m	LOCAL MEDIA TV NEW YORK, LLC
W20EF-D	KML/Fill/Text	20		LPD	LIC	-	NEW YORK	NY	US	0000053224	74502	6.02 kW	- m	LOCAL MEDIA TV NEW YORK, LLC
WCBS-TV	KML/Fill/Text	22	2	DRT	LIC	-	NEW YORK	NY	US	0000092488	9610	- kW	- m	-
WXNY-LD	KML/Fill/Text	23		LPD	LIC	-	NEW YORK	NY	US	0000182227	29231	3.25 kW	- m	WORD OF GOD FELLOWSHIP, INC.
WNYE-TV	KML/Fill/Text	24	25	DTV	LIC	-	NEW YORK	NY	US	0000143561	6048	180. kW	309.7 m	NEW YORK CITY DEPARTMENT OF INFORMATION TECHNO
W25FA-D	KML/Fill/Text	25		LPD	LIC	-	NEW YORK	NY	US	0000053181	130475	0.12 kW	- m	VENTURE TECHNOLOGIES GROUP LLC
WNYW	KML/Fill/Text	27	5	DTV	LIC	-	NEW YORK	NY	US	0000079881	22206	92.8 kW	496. m	FOX TELEVISION STATIONS, LLC
W25FA-D	KML/Fill/Text	28		LPD	STA	-	NEW YORK	NY	US	0000163551	130475	14.8 kW	- m	VENTURE TECHNOLOGIES GROUP LLC
WNYD-LD	KML/Fill/Text	29		LPD	LIC	-	NEW YORK	NY	US	0000203192	128222	2.56 kW	- m	VENTURE TECHNOLOGIES GROUP, LLC
WNYN-LD	KML/Fill/Text	29		LPD	STA	-	NEW YORK	NY	US	0000048137	74305	0.8 kW	- m	TVC NY LICENSE LLC
WNYN-LD	KML/Fill/Text	30		LPD	CP	-	NEW YORK	NY	US	0000232290	74305	15. kW	- m	TVC NY LICENSE LLC
WNYN-LD	KML/Fill/Text	30		LPD	STA	-	NEW YORK	NY	US	0000207470	74305	0.8 kW	- m	TVC NY LICENSE LLC
WNJJ-LD	KML/Fill/Text	30	40	LPD	CP	-	NEW YORK	NY	US	0000218568	167314	15. kW	- m	VENTURE TECHNOLOGIES GROUP, LLC
WNJJ-LD	KML/Fill/Text	30	40	LPD	LIC	-	NEW YORK	NY	US	0000194202	167314	0.085 kW	- m	VENTURE TECHNOLOGIES GROUP, LLC
WNYN-LD	KML/Fill/Text	30		LPD	STA	-	NEW YORK	NY	US	0000079868	74305	0.8 kW	- m	TVC NY LICENSE LLC
WHTV-LD	KML/Fill/Text	31	18	LPD	LIC	-	NEW YORK	NY	US	0000153808	127812	15. kW	- m	BRIDGE NEWS LLC
WMBQ-CD	KML/Fill/Text	32		DCA	LIC	-	NEW YORK	NY	US	0000221188	14322	0.008 kW	495.6 m	WNET
W33ET-D	KML/Fill/Text	33		LPD	LIC	-	NEW YORK	NY	US	0000213585	60554	15. kW	- m	MAJOR MARKET BROADCASTING OF NEW YORK INC.
WPXN-TV	KML/Fill/Text	34	31	DTV	LIC	-	NEW YORK	NY	US	0000086780	73356	170. kW	520. m	ION MEDIA LICENSE COMPANY, LLC
WNBC	KML/Fill/Text	35	4	DTV	LIC	-	NEW YORK	NY	US	0000221187	47535	575. kW	496. m	NBC TELEMUNDO LICENSE LLC
WCBS-TV	KML/Fill/Text	36	2	DTV	LIC	-	NEW YORK	NY	US	0000221185	9610	548. kW	520. m	CBS BROADCASTING INC.

*** 32 Records Retrieved ***

Call	---KML maps--	Channel	Virtual Channel	Service	Status	ATSC 3 (Nextgen TV)?	City	State	Country	File Number	FacilityID	ERP	HAAT	Licensee/Permittee
WOCK-CD	KML/Fill/Text	4		DCA	LIC	-	CHICAGO	IL	US	0000163766	35092	3. kW	- m	KM LPTV OF CHICAGO-13, L.L.C.
WRME-LD	KML/Fill/Text	6		LPD	LIC	Y	CHICAGO	IL	US	0000239876	128239	3. kW	- m	WLFM, LLC
WBBM-TV	KML/Fill/Text	12	2	DTV	LIC	-	CHICAGO	IL	US	0000234857	9617	10.9 kW	500.4 m	CBS BROADCASTING INC.
WBBM-TV	KML/Fill/Text	12	2	DTV	CP	-	CHICAGO	IL	US	0000207079	9617	30. kW	490.8 m	CBS BROADCASTING INC.
WBBM-TV	KML/Fill/Text	12	2	DTV	APP	Y	CHICAGO	IL	US	0000249867	9617	29.5 kW	500.4 m	CBS BROADCASTING INC.
WMEU-CD	KML/Fill/Text	18		DCA	LIC	-	CHICAGO	IL	US	0000086889	168662	15. kW	- m	WEIGEL BROADCASTING CO.
WMEU-CD	KML/Fill/Text	18		DCA	CP	-	CHICAGO	IL	US	0000196962	168662	15. kW	- m	WEIGEL BROADCASTING CO.
WGN-TV	KML/Fill/Text	19	9	DTV	LIC	-	CHICAGO	IL	US	0000235154	72115	645. kW	497.7 m	TRIBUNE MEDIA COMPANY
WWME-CD	KML/Fill/Text	20		DCA	LIC	-	CHICAGO	IL	US	0000086882	71425	15. kW	- m	CHANNEL 23 LIMITED PARTNERSHIP
WWME-CD	KML/Fill/Text	20		DCA	CP	-	CHICAGO	IL	US	0000196954	71425	15. kW	- m	CHANNEL 23 LIMITED PARTNERSHIP
WLS-TV	KML/Fill/Text	22	7	DTV	LIC	-	CHICAGO	IL	US	0000232100	73226	1000. kW	518. m	WLS TELEVISION, INC.
WCIU-TV	KML/Fill/Text	23	26	DTV	CP	-	CHICAGO	IL	US	0000196941	71428	1000. kW	453. m	WCIU-TV LIMITED PARTNERSHIP
WCIU-TV	KML/Fill/Text	23	26	DTV	LIC	-	CHICAGO	IL	US	0000102906	71428	1000. kW	473. m	WCIU-TV LIMITED PARTNERSHIP
WFLD	KML/Fill/Text	24	32	DTV	CP	-	CHICAGO	IL	US	0000072366	22211	1000. kW	520. m	FOX TELEVISION STATIONS, LLC
WTTW	KML/Fill/Text	25	11	DTV	LIC	-	CHICAGO	IL	US	0000193623	10802	250. kW	496. m	WINDOW TO THE WORLD COMMUNICATIONS, INC.
WPVN-CD	KML/Fill/Text	26	24	DCA	LIC	-	CHICAGO	IL	US	0000106475	168237	15. kW	- m	HC2 STATION GROUP, INC.
WMAQ-TV	KML/Fill/Text	29	5	DTV	LIC	-	CHICAGO	IL	US	0000236668	47905	350. kW	508. m	NBC TELEMUNDO LICENSE LLC
WSNS-TV	KML/Fill/Text	29	44	DTV	LIC	-	CHICAGO	IL	US	0000053195	70119	350. kW	508. m	NBC TELEMUNDO LICENSE LLC
WDCI-LD	KML/Fill/Text	30		LPD	LIC	-	CHICAGO	IL	US	BLDTL-20120131AAW	67898	15. kW	- m	WORD OF GOD FELLOWSHIP, INC
WDCI-LD	KML/Fill/Text	30		LPD	CP	-	CHICAGO	IL	US	0000106360	67898	.85 kW	- m	WORD OF GOD FELLOWSHIP, INC
WFLD	KML/Fill/Text	31	32	DTV	LIC	-	CHICAGO	IL	US	0000235116	22211	1000. kW	475. m	FOX TELEVISION STATIONS, LLC
WESV-LD	KML/Fill/Text	31		LPD	LIC	-	CHICAGO	IL	US	0000125079	68043	15. kW	- m	ESTRELLA TELEVISION LICENSE LLC
W31EZ-D	KML/Fill/Text	31		LPD	LIC	-	CHICAGO	IL	US	0000124951	61692	15. kW	- m	HC2 STATION GROUP, INC.
WMAQ-TV	KML/Fill/Text	33	5	DTV	CP	-	CHICAGO	IL	US	0000080396	47905	398. kW	509. m	NBC TELEMUNDO LICENSE LLC
WCPX-TV	KML/Fill/Text	34	38	DTV	LIC	-	CHICAGO	IL	US	0000087607	10981	400. kW	510. m	ION TELEVISION LICENSE, LLC

*** 25 Records Retrieved ***

Call	---KML maps--	Channel	Virtual Channel	Service	Status	ATSC 3 (Nextgen TV)?	City	State	Country	File Number	FacilityID	ERP	HAAT	Licensee/Permittee
KURK-LD	KML/Fill/Text	3		LPD	LIC	-	SAN FRANCISCO	CA	US	0000022172	182643	2.5 kW	- m	ONE MINISTRIES, INC.
KURK-LD	KML/Fill/Text	3		LPD	CP	-	SAN FRANCISCO	CA	US	0000200816	182643	3. kW	- m	ONE MINISTRIES, INC.
KRON-TV	KML/Fill/Text	7	4	DTV	LIC	Y	SAN FRANCISCO	CA	US	0000238930	65526	50. kW	507.2 m	NEXSTAR MEDIA INC.
KPJC-LD	KML/Fill/Text	11	12	LPD	LIC	-	SAN FRANCISCO	CA	US	0000223119	182962	0.075 kW	- m	JEFF CHANG
KGO-TV	KML/Fill/Text	12	7	DTV	LIC	-	SAN FRANCISCO	CA	US	0000212635	34470	47. kW	520.5 m	KGO TELEVISION, INC.
KQTA-LD	KML/Fill/Text	13	15	LPD	LIC	-	SAN FRANCISCO	CA	US	0000053612	182960	.039 kW	- m	ONE MINISTRIES, INC.
KDTS-LD	KML/Fill/Text	14		LPD	LIC	-	SAN FRANCISCO	CA	US	0000192357	167032	15. kW	- m	WORD OF GOD FELLOWSHIP, INC.
KMMC-LD	KML/Fill/Text	14	30	LPD	APP	-	SAN FRANCISCO	CA	US	0000194156	30977	15. kW	- m	DIYA TV, INC.
KQTA-LD	KML/Fill/Text	14	15	LPD	APP	-	SAN FRANCISCO	CA	US	0000193115	182960	15. kW	- m	ONE MINISTRIES, INC.
KMMC-LD	KML/Fill/Text	14	30	LPD	CP	-	SAN FRANCISCO	CA	US	0000193890	30977	15. kW	- m	DIYA TV, INC.
KMMC-LD	KML/Fill/Text	14	30	LPD	AMD	-	SAN FRANCISCO	CA	US	0000177351	30977	7.5 kW	- m	DIYA TV, INC.
KQTA-LD	KML/Fill/Text	14	15	LPD	CP	-	SAN FRANCISCO	CA	US	0000193031	182960	15. kW	- m	ONE MINISTRIES, INC.
KTSF	KML/Fill/Text	20	26	DTV	LIC	-	SAN FRANCISCO	CA	US	0000113739	37511	475. kW	701.3 m	LINCOLN BROADCASTING COMPANY, A CALIFORNIA LP
KDTV-DT	KML/Fill/Text	20	14	DTV	LIC	-	SAN FRANCISCO	CA	US	0000212320	33778	475. kW	701.3 m	KDTV LICENSE PARTNERSHIP, G.P.
KMTP-TV	KML/Fill/Text	21	32	DTV	LIC	-	SAN FRANCISCO	CA	US	0000137431	43095	15. kW	- m	MINORITY TELEVISION PROJECT
KOFY-TV	KML/Fill/Text	21	20	DTV	LIC	-	SAN FRANCISCO	CA	US	0000186488	51189	15. kW	- m	STRYKER MEDIA 2 LLC
KCNZ-CD	KML/Fill/Text	21	28	DCA	LIC	-	SAN FRANCISCO	CA	US	0000186215	52887	15. kW	- m	POQUITO MAS COMMUNICATIONS LLC
KPYX	KML/Fill/Text	28	44	DTV	LIC	-	SAN FRANCISCO	CA	US	0000112987	69619	1000. kW	490.3 m	SAN FRANCISCO TELEVISION STATION KBCW INC
KPIX-TV	KML/Fill/Text	29	5	DTV	LIC	-	SAN FRANCISCO	CA	US	0000212264	25452	1000. kW	490.3 m	CBS BROADCASTING INC.
KQED	KML/Fill/Text	30	9	DTV	LIC	-	SAN FRANCISCO	CA	US	0000040845	35500	1000. kW	511.7 m	KQED INC.
KCNS	KML/Fill/Text	32	38	DTV	LIC	-	SAN FRANCISCO	CA	US	0000108769	71586	1000. kW	511.7 m	RNN NATIONAL, LLC
KMTP-TV	KML/Fill/Text	32	32	DTV	CP	-	SAN FRANCISCO	CA	US	0000140842	43095	1000. kW	511.7 m	MINORITY TELEVISION PROJECT
KGO-TV	KML/Fill/Text	35	7	DRT	LIC	-	SAN FRANCISCO	CA	US	BLCDT-20111201NYO	34470	- kW	- m	-

Appendix B: High-Frequency (HF) International Broadcasting

Also known as "shortwave" broadcasting, HF broadcasting is an FCC-licensed radio service intended for international transmission to foreign countries. Fifteen licensed HF stations operate between 5.950 MHz and 26.100 MHz. The required minimum transmit power is 50 kilowatts (kW), and a directional antenna with a 10 dB minimum gain is mandatory.

Table B1 provides details on the location, the maximum transmit power, and the maximum antenna gain for each site. Additionally, the safe stand-off distances are calculated based on the recommended 50 V/m tolerance level for the HIRF Band 4, which includes the HF radio band. As shown in the table, the safe stand-off distance can extend slightly beyond one kilometer. This is considered acceptable since most locations are in non-urban areas with few other avoidance zones nearby.

Table B1: 15 FCC Licensed Shortwave Broadcast Stations

	Power (KW)	**Antenna Gain (dB)**	**R(m) at 50 V/m**	**Latitude**	**Longitude**
KHBN Medorn, Aimeliik, Palau – (T8BZ)	100	17	245	07 27 22 N	134 28 24 E
KNLS Anchor Point, AK	100	21.7	421	59 44 58 N	151 43 56 W
KSDA Agat, GU;	100	20.0	346	13 20 28 N	144 38 56 E
KTWR Agana, GU;	250	21.7	666	13 16 38 N	144 40 16 E
KVOH Rancho Simi Valley, CA	50	14.5	130	34 15 23 N	118 38 29 W
WBCQ Monticello, ME	500	20	775	46 20 30 N	067 49 40 W
WEWN Vandiver, AL	500	22.5	1033	33 30 13 N	086 28 27 W
WHRI Furman, SC	500	22	975	32 41 03 N	081 07 50 W
WINB Red Lion, PA	50	20.0	245	39 54 22 N	076 34 56 W
WJHR Milton, FL	50	16.24	159	30 39 03 N	087 05 27 W
WMLK Bethel, PA	300	22.5	800	40 28 46 N	076 16 47 W
WRMI Okeechobee, FL	100	22	436	27 27 30 N	080 56 00 W
WRNO New Orleans, LA	Unlisted	14		29 50 10 N	090 06 57 W
WTWW Lebanon, TN	100	12	138	36 16 35 N	086 05 58 W
WWCR Nashville, TN	100	14.5	184	36 12 30 N	086 53 38 W

Appendix C: Airports with NEXRAD and TDWR Stations

This appendix lists airports co-located with NOAA NEXRAD or TDWR weather radars, where large avoidance zones may impact VTOL operations - especially if Airport Surveillance Radars (ASRs) are also nearby. The list was developed by visually comparing mapped TDWR and NEXRAD sites with airport locations. Only one general aviation airport hosts a TDWR station; the others are associated with NEXRAD systems. Among these, Dulles is the only large hub, while Buffalo Niagara, Cleveland, and Indianapolis are medium hubs; the rest are small hubs or general aviation airports.

Figs. C1–C7 show airport maps with nearby NEXRAD stations, and corresponding HIRF avoidance radii based on a 1000 V/m threshold. When combined with ASR-9 avoidance zones, these areas may restrict VTOL operations. As noted in Table C3, a higher tolerance of up to 2000 V/m in the 2–4 GHz band may be required to reduce the avoidance area size. The avoidance zone diameter would be reduced by half.

<u>NEXRAD</u>

Alabama

• Mobile Regional Airport – Regional Airport

• Shelby County Airport – General Aviation Airport

Arizona

• Phoenix-Mesa Gateway Airport – Small Hub

Arkansas

• North Little Rock Municipal Airport – General Aviation Airport

California

• Hanford Municipal Airport – General Aviation Airport

• Oroville Municipal Airport – General Aviation Airport

Colorado

• Cheyenne Regional Airport – Regional Airport

• Colorado Air and Space Port – General Aviation Airport

Florida

• Jacksonville International Airport – Small Hub

• Tallahassee International Airport – Regional Airport

Georgia

• Peachtree City – Falcon Field Airport – General Aviation Airport

Illinois

• Lewis University Airport – General Aviation Airport

• Logan County Airport – General Aviation Airport

Indiana

• Indianapolis International Airport – Medium Hub

Kansas

• Dodge City Regional Airport – Regional Airport

• Goodland Municipal Airport – General Aviation Airport

• Wichita Dwight D. Eisenhower National Airport – Small Hub

Louisiana

• Lake Charles Regional Airport

Michigan

• Gerald R. Ford International Airport – Small Hub

Minnesota

• Duluth International Airport – Regional Airport

Missouri

• Springfield-Branson National Airport – Regional Airport

Montana

• Great Falls International Airport – Regional Airport

• Wokal Field – Glasgow International Airport – Regional Airport

Nebraska

• Logan County Airport – General Aviation Airport

New Mexico

• Dona Ana County International Jetport – General Aviation Airport

New York

• Buffalo Niagara International Airport – Medium Hub

• Greater Binghamton Airport – Regional Airport

North Dakota

• Bismarck Municipal Airport – Regional Airport

Ohio

• Airborne Airpark, Wilmington – General Aviation Airport

• Cleveland Hopkins International Airport – Medium Hub

Oklahoma

• Frederick Municipal Airport – General Aviation Airport

• Max Westheimer Airport – General Aviation Airport

• Vance Air Force Base – Military Facility

Oregon

• Eastern Oregon Regional Airport – Regional Airport

South Carolina

• Columbia Metropolitan Airport – Small Hub

• Greenville-Spartanburg Int'l Airport – Small Hub

South Dakota

• Aberdeen Regional Airport – Regional Airport

• Sioux Falls Regional Airport – Small Hub

Tennessee

• Millington Regional Jetport – General Aviation Airport

Texas

• Corpus Christi International Airport – Regional Airport

• Fort Worth Spinks Airport – General Aviation Airport

• Lubbock Preston Smith International Airport – Small Hub

• Midland International Air and Space Port – Small Hub

• New Braunfels Municipal Airport – General Aviation Airport

• Rick Husband Amarillo International Airport – Small Hub

• San Angelo Regional Airport

Virginia

• Dulles International Airport – Large Hub

• Wakefield Municipal Airport – General Aviation Airport

Wisconsin

• Austin Straubel International Airport – Regional Airport

Wyoming

• Central Wyoming Regional Airport – Regional Airport

<u>TDWR</u>

Texas

• Pearland Regional Airport (KLVJ) – General Aviation Airport

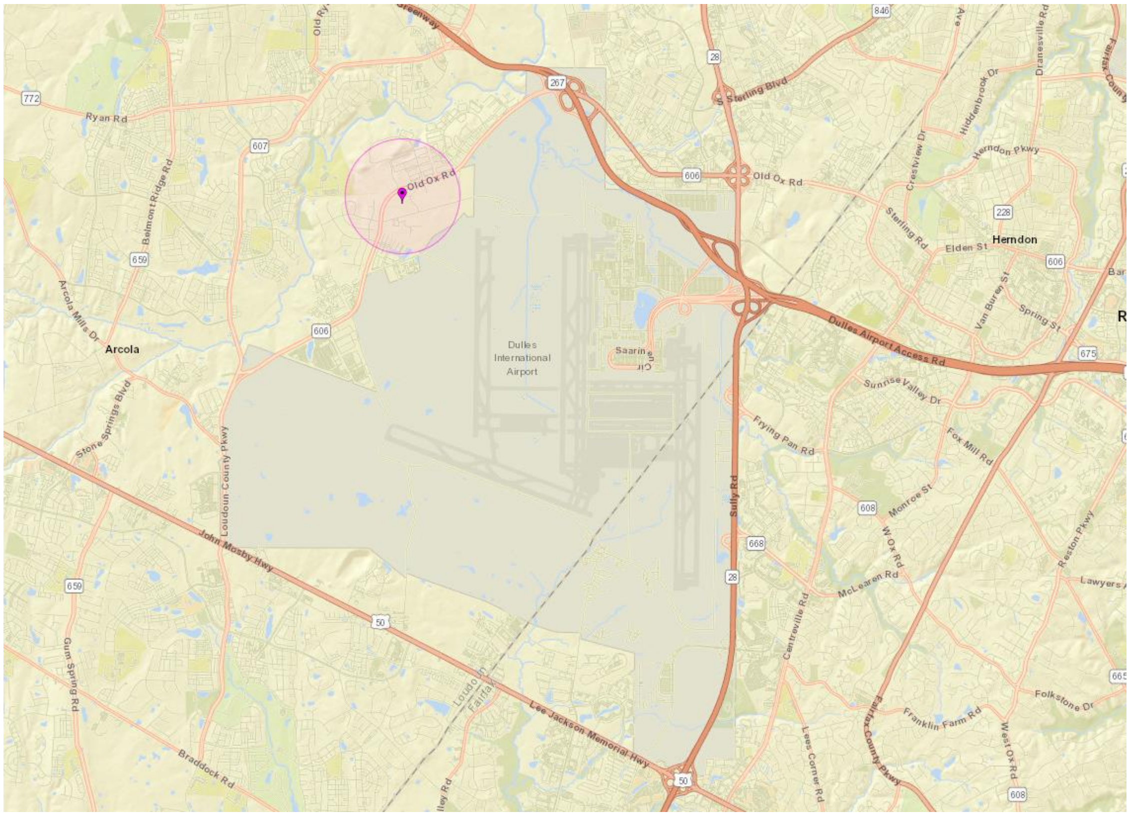

Fig. C1: NEXRAD HIRF radius at Dulles Inter. Airport (Tolerance = 1000 V/m).

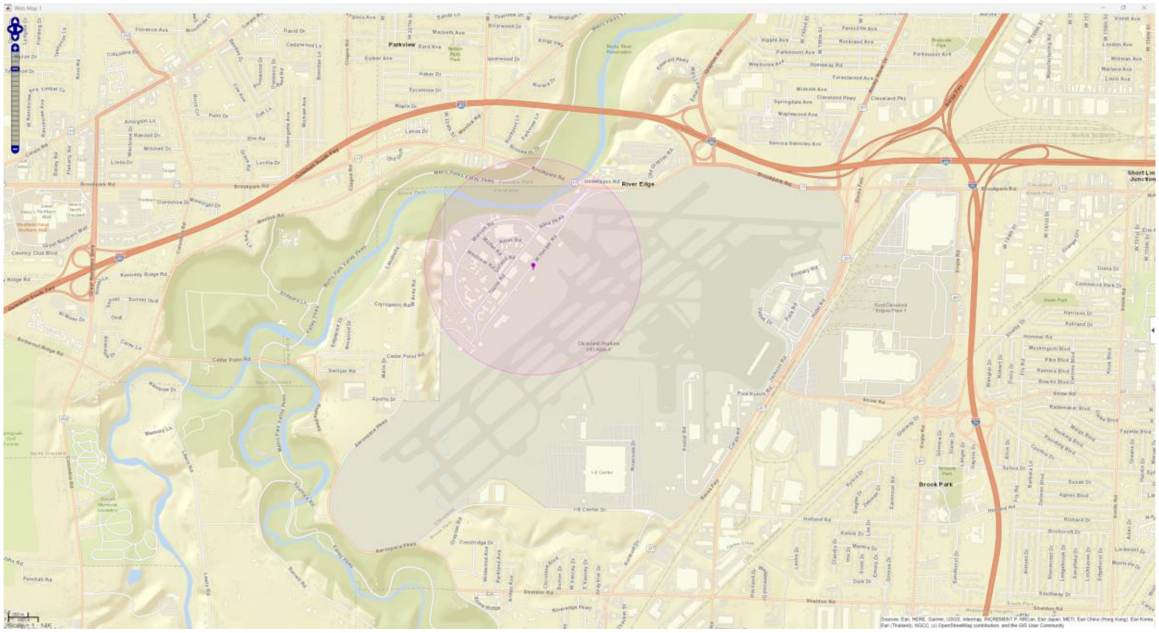

Fig. C2: NEXRAD HIRF radius at Cleveland Hopkins Airport (Tolerance = 1000 V/m).

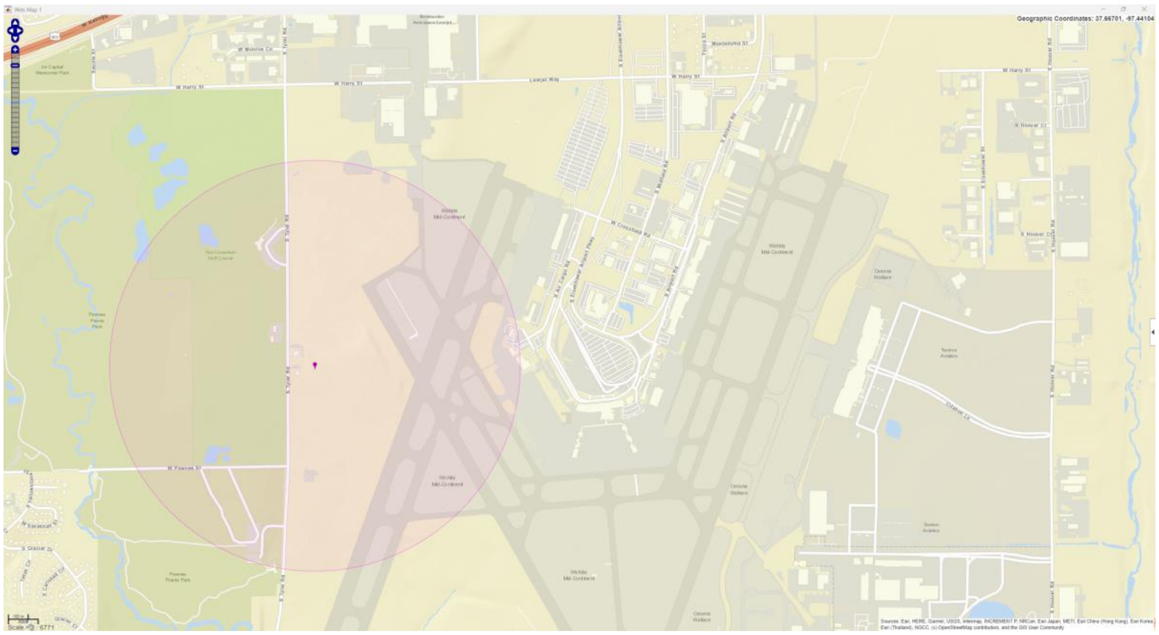

Fig: C3: NEXRAD HIRF radius at Wichita Airport (Tolerance = 1000 V/m).

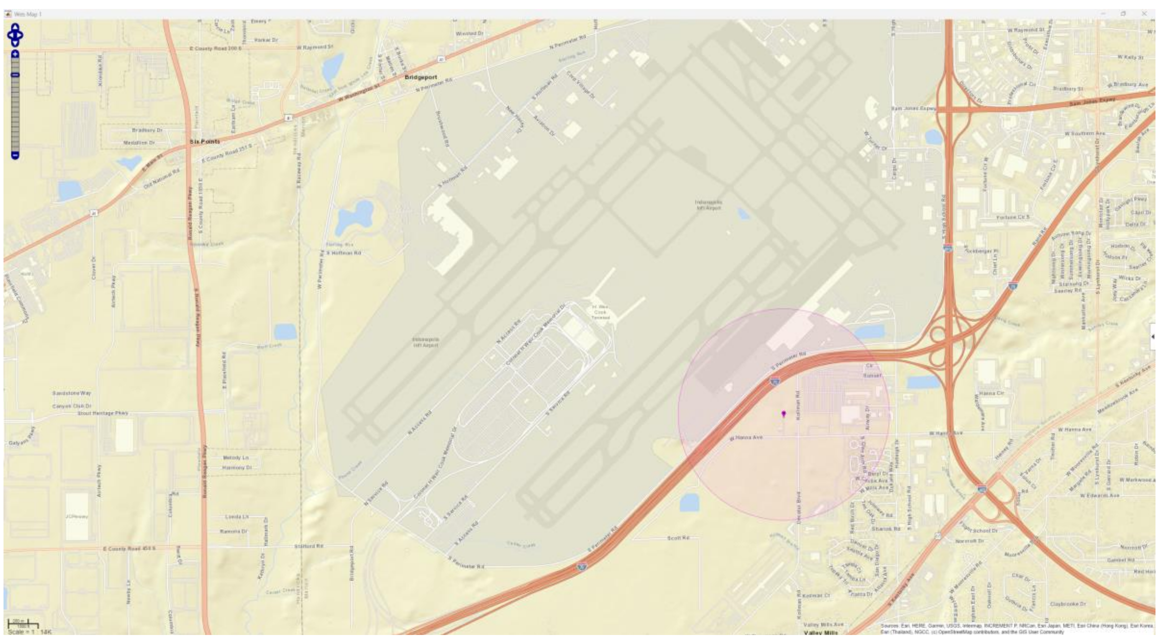

Fig. C4: NEXRAD HIRF radius at Indianapolis Airport (Tolerance = 1000 V/m).

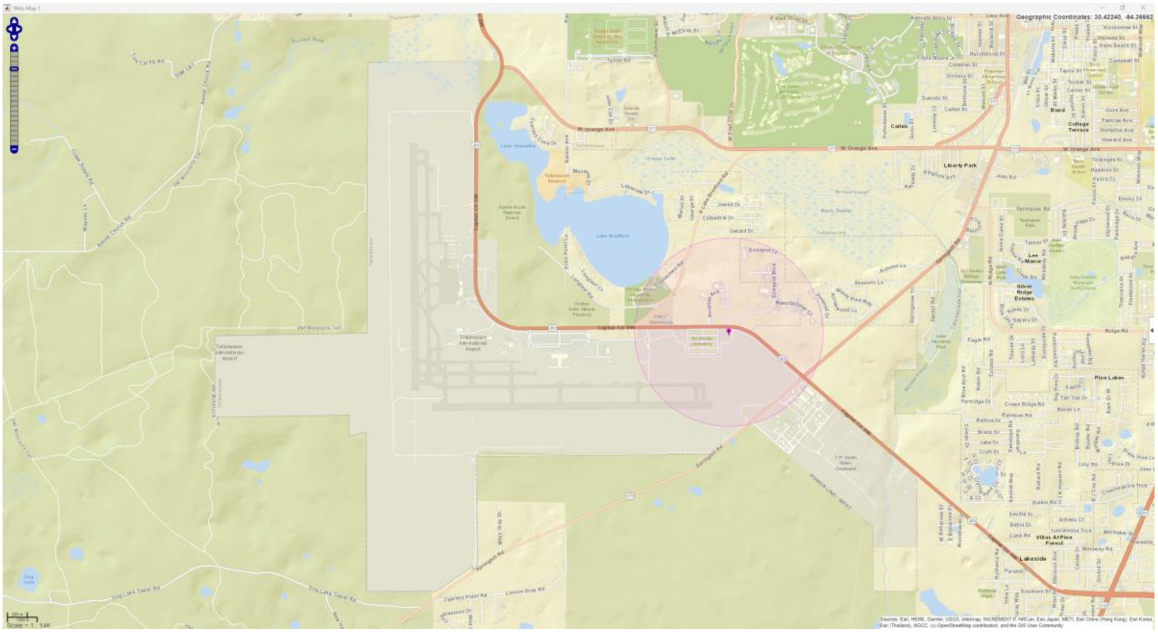

Fig. C5: NEXRAD HIRF radius at Tallahassee Airport, FL. (Tolerance = 1000 V/m).

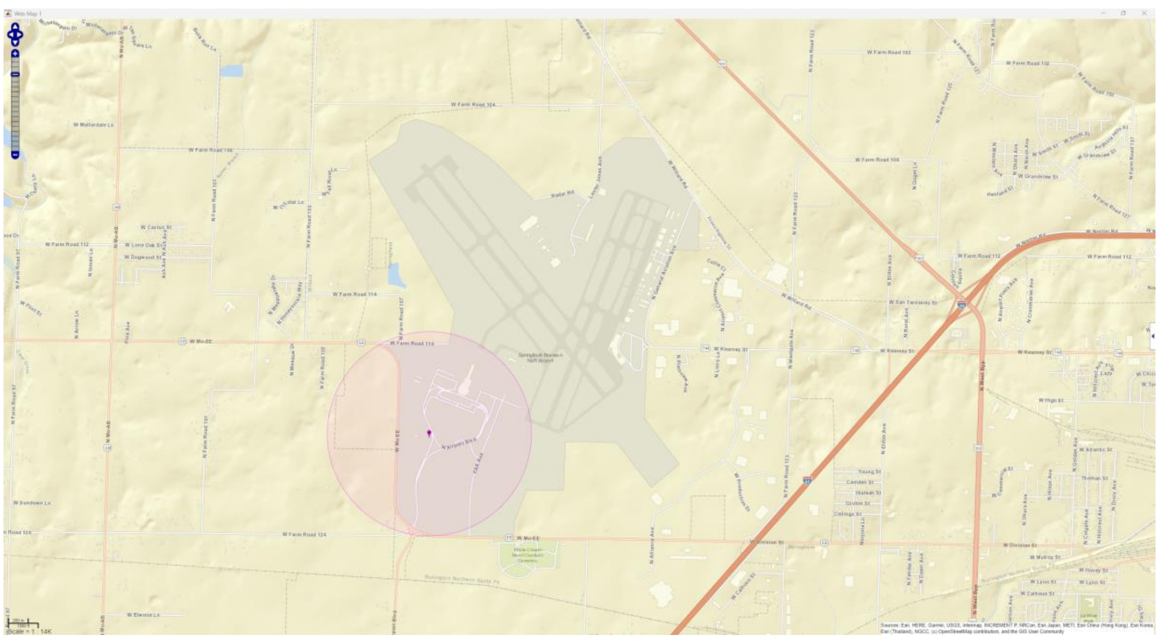

Fig. C6: NEXRAD HIRF radius at Springfield-Branson National Airport (Tolerance = 1000 V/m).

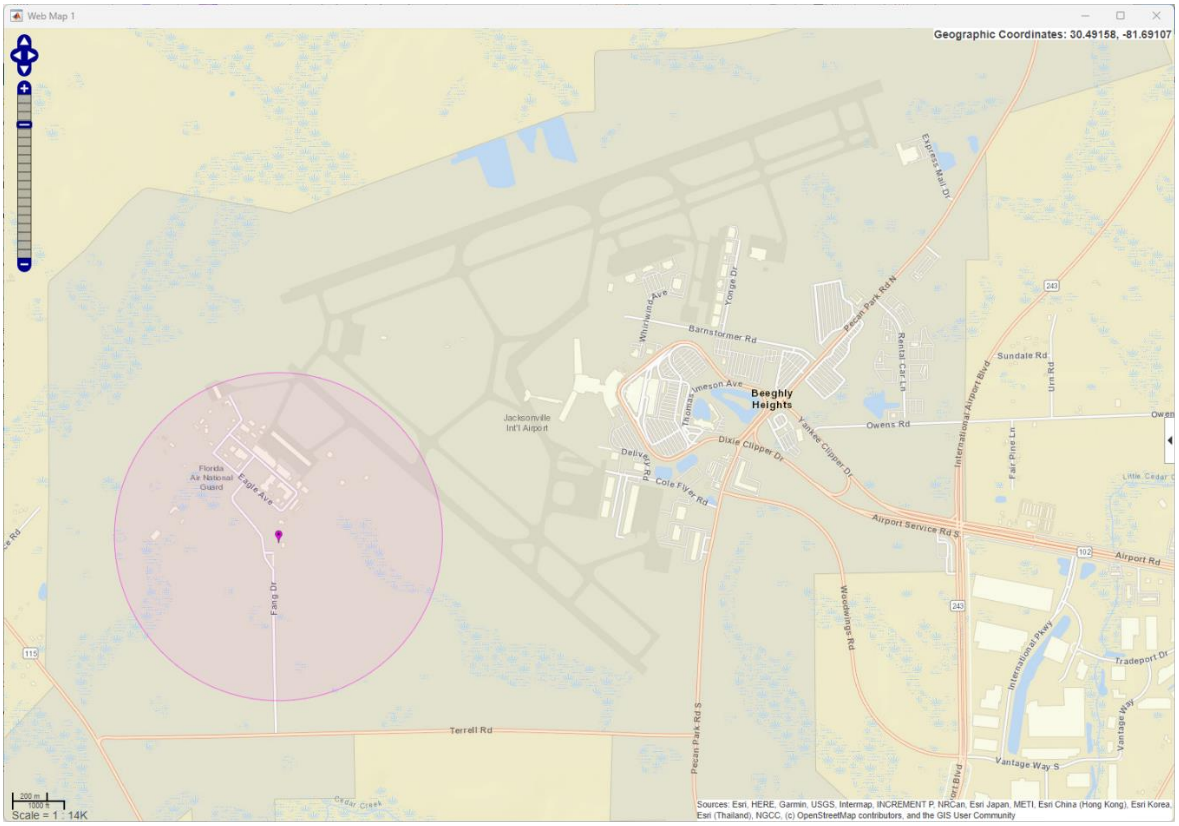

Fig. C7: NEXRAD HIRF radius at Jacksonville Int'l Airport (Tolerance = 1000 V/m).