DF ACCURACY REQUIREMENTS FOR MONITORING STATIONS

White paper | Version 01.00 | Philipp Strobel

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INTRODUCTION

Radio direction finders (DF) in spectrum monitoring are widely used to locate transmitters such as radio frequency (RF) interferers and unlicensed broadcasting stations.

In fixed monitoring stations (FMS), two or more DFs are installed on masts and allow geolocation of transmitters via triangulation. In mobile monitoring stations (MMS), the DF is installed on a vehicle roof and allows geolocation of transmitters on the move via homing. In transportable monitoring stations (TMS), two or more DFs are temporarily installed at exposed sites and allow geolocation of transmitters via triangulation.

Other methods for locating transmitters include time difference on arrival (TDOA) and power on arrival (POA). In this document, we focus on triangulation since this method is used in the vast majority of use cases.

Following international standards, DF accuracy refers to system DF accuracy, i.e. the average difference between the nominal direction of arrival and the DF result from the DF system connected to a DF antenna in a reflection-free environment.

The system DF accuracy should not be confused with the instrument DF accuracy (DF accuracy of the DF processor without a DF antenna) or operational DF accuracy (DF accuracy of the installed DF system in the operational environment including reflections).

GEOLOCATION ACCURACY

Typically, geolocation via triangulation provides a rough estimation of the area in which the search is continued with MMS and handheld equipment. This area is referred to as the area of uncertainty. The geolocation accuracy defines the size of the area of uncertainty in which the transmitter of interest is located. In general, the wider the area of uncertainty, the longer it will take to actually find the transmitter of interest. This is because more buildings fall inside this area and must be checked to see if they host the transmitter.

In practice, the signal of interest can typically only be received by one or two monitoring stations. This is because the signals of interest tend to be weak and for economic reasons, monitoring stations have to cover large areas. We will focus on the geolocation performance with two monitoring stations.

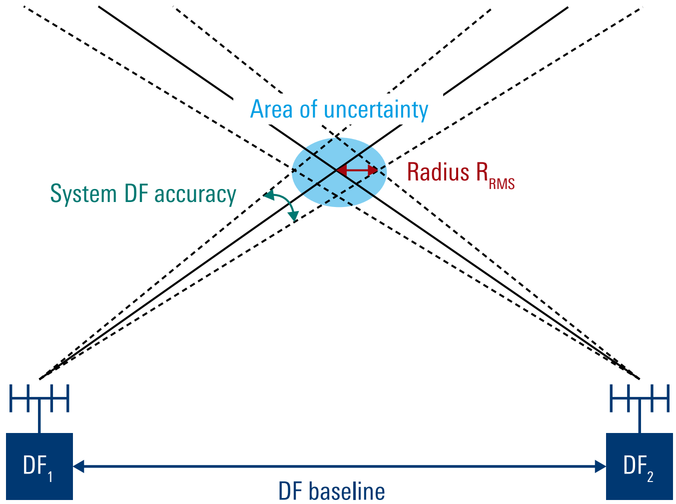
The calculation of the size of the area of uncertainty depends on several parameters and tends to be complex. In the special case that the distance to the transmitter equals the DF baseline and two DFs have identical system DF accuracy, the radius of the area of uncertainty can be expressed as [1; Fig. 295/296]:

$$R_{RMS} = 0.035 \times \sigma \times B$$

where R_{RMS} is the longest radius of the error ellipse in meters, σ is the system DF accuracy in degrees (RMS) and B is the DF baseline in meters, i.e. the distance between the monitoring stations.

Fig. 1 shows an example with two DF stations that helps visualize the parameters involved.

Fig. 1: Area of uncertainty with two DF stations



DF ACCURACY REQUIREMENTS

As shown above, the system DF accuracy has a significant influence on geolocation accuracy. It is also the only parameter that can be influenced by the operator (by selecting accurate DF systems). All other parameters depend on the location of the transmitter and cannot be influenced by the operator.

Fixed and transportable monitoring stations

The wider the area of uncertainty, the higher the number of buildings inside it. The more buildings, the more time it takes to find the particular building that hosts the transmitter of interest. It would therefore be beneficial to have a rough estimate of the number of buildings involved.

Obviously, the number of buildings strongly depends on the area of interest. Geolocation of transmitters typically takes place in urban areas. To get an idea of the scale, the number of buildings was estimated for Brooklyn/New York City. According to [2], there were 340 250 buildings in Brooklyn in January 2020. According to [3], the area of Brooklyn has a size of approx. 183.4 km². This translates to approx. 1856 buildings per square kilometer.

Table 1 shows the size of the area of uncertainty and the number of buildings inside this area in Brooklyn for different scenarios with respect to system DF accuracy and distance to the transmitter. In order to keep it simple, the area of uncertainty is considered circular. Figure 2 shows a simulation of the above two scenarios presented on a map of Brooklyn [4].

Table 1

System DF accuracy	5 km		10 km		20 km	
	Size of area	**Number of buildings**	**Size of area**	**Number of buildings**	**Size of area**	**Number of buildings**
1° RMS	approx. 0.1 km²	approx. 186	approx. 0.4 km²	approx. 742	approx. 1.5 km²	approx. 2860
3° RMS	approx. 0.9 km²	approx. 1670	approx. 3.5 km²	approx. 6680	approx. 14 km²	approx. 25 710
5° RMS	approx. 2.4 km²	approx. 4640	approx. 8.8 km²	approx. 18 560	approx. 38 km²	approx. 71 430

(1) 1° RMS system DF accuracy **approx. 186 buildings**

(2) 5° RMS system DF accuracy **approx. 4640 buildings**

Fig. 2: Comparison of the areas of uncertainty (simplified) for a transmitter at a distance of 5 km

From Table 1 and Fig. 2, the following conclusion can be drawn: as soon as the distance to the transmitter significantly exceeds 10 km and/or as soon as the system DF accuracy exceeds 1° RMS, thousands of buildings fall into the area of uncertainty. In order to avoid having to search for the transmitter of interest inside large areas with thousands of buildings, accurate monitoring stations with 1° RMS system DF accuracy have to be used.

In some applications, such as geolocation of sporadic interferers, a few seconds of emission might be all that is available to locate the transmitter. In such applications, it is not enough to choose accurate monitoring stations. The distance to the transmitter should also be significantly less than 10 km.

Mobile monitoring stations operated on the move

For homing-in on the transmitter of interest, mobile monitoring stations are typically used on the move in urban areas. Most of the time, buildings block the line-of-sight to the transmitter of interest. And strong reflections from surrounding buildings arrive at the DF station, causing severe DF errors. The system DF accuracy adds to these DF errors. However, when operated on the move, the system DF accuracy is less important for MMS than it is for FMS and TMS.

Mobile monitoring stations operated quasi-stationary

For geolocation of sporadic interferers and for monitoring at major events, MMS are deployed temporarily at exposed sites in a low-reflective environment. In such use cases, the considerations made above for FMS and TMS also apply to MMS, i.e. a system DF accuracy of 1° RMS is required.

REQUIREMENTS IN LINE WITH INTERNATIONAL STANDARDS

International Telecommunication Union (ITU)

The ITU Handbook on Spectrum Monitoring gives recommendations regarding the DF accuracy of monitoring stations [5], see Table 2.

Table 2

Parameter	Specification	Reference
System DF accuracy in the HF range		
Fixed monitoring stations	1° RMS	ITU Handbook on Spectrum Monitoring, edition 2010, table 3.4-1
Mobile monitoring stations	5° RMS	
System DF accuracy in the VHF/UHF range		
Fixed monitoring stations	1° RMS	ITU Handbook on Spectrum Monitoring, edition 2010, table 3.4-2
Mobile monitoring stations	3° RMS	
Position of the lightning rod	vertically above the antenna system/array	ITU Handbook on Spectrum Monitoring, edition 2010, section 2.6.2.4.6
Verification of system DF accuracy	in line with Recommendation ITU-R SM.2060	Recommendation ITU-R SM.2060

International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)

In safety critical applications such as vessel traffic systems (VTS), even a single short distress call must be measured accurately since it might be the only information available to save the lives of the people involved. Consequently, for standard VTS, a maximum DF error of ±1.5° is recommended [6]. This translates to a required system DF accuracy of approx. 1° RMS.

HOW TO MEET THE REQUIREMENTS IN PRACTICE

In general, it is possible to meet above-mentioned DF accuracy requirements in practice. However, this requires careful selection of the DF antenna site and a lightning protection concept that does not affect DF accuracy.

Antenna site selection

Careful selection of the DF antenna site is of utmost importance to achieve an operational DF accuracy of 1° RMS. The ITU Handbook on Spectrum Monitoring, edition 2010, section 2.6 gives recommendations on siting of monitoring stations. In particular, the minimum distances between obstacles and DF antenna should be considered.

Lightning protection

Typically, FMS must be protected against direct lightning strikes with a lightning rod. In principle, any conductive structure in close vicinity to the DF antenna affects the DF accuracy. The influence of the lightning rod on the DF accuracy heavily depends on the design concept of the DF antenna. For DF antennas with integrated lightning protection mounted vertically above the antenna array, the influence of the lightning rod is symmetrical and suppressed with ferrite rings. Consequently, the influence of the lightning protection on DF accuracy is negligible.

For DF antennas without integrated lightning protection, the lightning rod must be installed beside the antenna by using a side-arm. In this case, the influence of the lightning rod is asymmetrical and hardly reduced by using ferrite rings. The lightning rod generates a strong reflection, especially at frequencies where the structure is in resonance, i.e. in the VHF range. This reflection will significantly decrease the overall DF accuracy and causes DF errors of more than 20° based on the frequency and angle of arrival (AoA). The DF accuracy is affected in all directions, not only in the direction of the lightning rod.

Table 3 shows the influence of lightning protection on the system DF accuracy for DF antennas with and without integrated lighting protection.

Table 3

Parameter	Lightning protection mounted vertically above the DF antenna	Lightning protection mounted at the side of the DF antenna
System DF accuracy as specified in the data sheet (not including lightning protection)	1° RMS	1° RMS
System DF accuracy in operation (including lightning protection)	1° RMS	5° RMS (VHF)
		2° RMS (UHF)
Maximum DF error	up to 3°	up to 20° and higher

SUMMARY

The system DF accuracy specification defines the DF accuracy limits and the geolocation accuracy of the subsequent triangulation network.

Both practical considerations and international standards recommend a minimum system DF accuracy of 1° RMS for fixed and transportable monitoring stations as well as for mobile monitoring stations that are deployed temporarily.

Careful selection of the DF antenna site ensures that the system DF accuracy is achieved in the real operational environment.

For mobile monitoring stations operated on the move, system DF accuracy requirements are less stringent since such systems are typically used in urban multipath environments. Here, DF errors from reflections tend to be significantly higher than the system DF accuracy.

The recommended system DF accuracy includes possible DF errors from lightning protection (where applicable). This requires that the lightning rod be mounted vertically above the DF antenna in line with the ITU Handbook on Spectrum Monitoring.

In principle, DF systems with side-arm lightning protection cannot meet the 1° RMS due to reflections from the lightning rod.

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[3] Wikimedia Foundation, Inc., www.wikipedia.com

[4] www.openstreetmap.com

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[6] Recommendation IALA V-128, International Association of Marine Aids to Navigation and Lighthouse Authorities

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