



Report ITU-R RS.2185
(10/2010)

**Study on compatibility between “arrival
time difference” (ATD) stations of the
meteorological aids service and stations
of the radionavigation service in the
frequency band 9 to 14 kHz**

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***Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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1 Executive summary

This Report outlines the results of studies into the work seeking to define sharing criteria to manage compatibility between transmitting stations of the radionavigation services and passive arrival time difference (ATD) receivers operating in the meteorological service in the frequency band below 20 kHz.

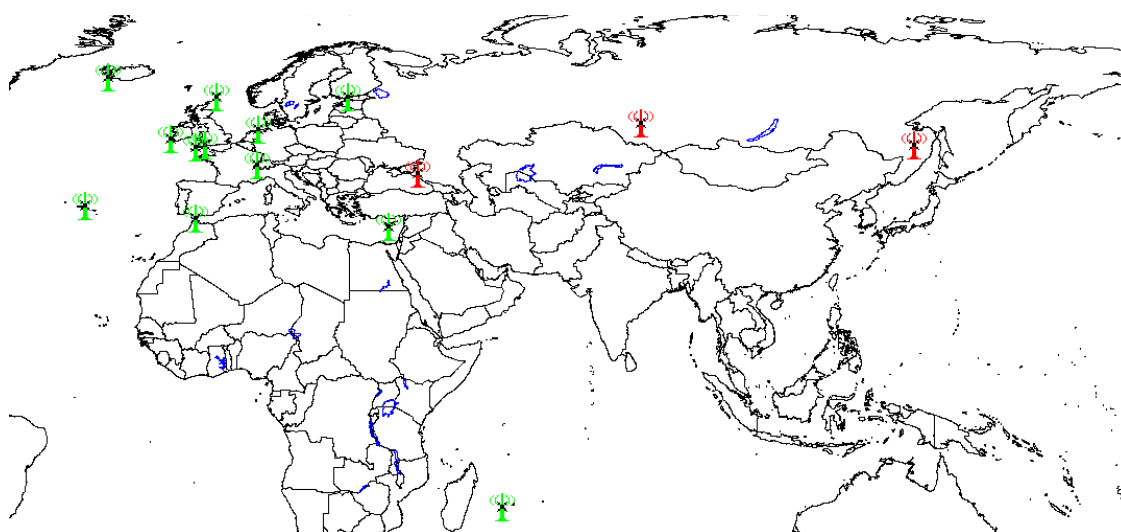
It discusses various issues and aspects of VLF propagation and concludes on the sharing and regulatory management aspects of ATD sensors and radionavigation services within the frequency band under discussion.

The findings, reflecting the real life sharing environment for many years, are that sharing between both services is a high possibility and practicality. Notwithstanding the technical aspects discussed herein, this is partially due to the nature of deployment characteristics of both services, and interference mitigation implemented by the arrival time difference system of the meteorological aids service.

2 ATD and radionavigation station deployments at June 2010

Figure 1 shows the location of each of the existing ATD receiver locations (shown in green) and known RNAV transmitter locations (shown in red).

FIGURE 1
ATD receiver and RNAV transmitter locations



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Actual ATD and RNAV site locations are shown in Tables 1 and 2.

TABLE 1
ATD receiver site locations

Site name	Latitude (decimal)	Longitude (decimal)
Valentia	51.939719N	10.244534W
Norderney	53.712421N	7.152314E
Exeter	50.728043N	3.475605W
Lerwick	60.139419N	1.185009W
Akrotiri	34.587151N	32.989052E
Gibraltar	36.152706N	5.348185W
Keflavik	63.968330N	22.614094W
Helsinki	60.203932N	24.961027E
La Reunion	20.896791S	55.485258E
Azores	38.658939N	27.223078W
Payerne	46.812123N	6.943854E
Camborne	50.218553N	5.327223W

TABLE 2
Radionavigation site locations

Site name	Latitude (decimal)	Longitude (decimal)
Komsomolsk Na Amure	50.5667N	136.96667E
Krasnodar	45.0333N	38.65E
Novosibirsk	55.0667N	82.9667E

3 Geographical separation between stations

The physical separation distance between each ATD receiver and each of the RNAV transmitters is also shown in Table 3.

TABLE 3
Separation distances between ATD and RNAV site locations

ATD receiver site	Separation distance to RNAV site (km)		
	Komsomolsk Na Amure	Krasnodar	Novosibirsk
Valentia	8 216	3 616	5 707
Norderney	7 520	2 453	4 668
Exeter	8 156	3 613	5 445
Lerwick	7 154	3 106	4 705
Akrotiri	7 994	1 259	4 428
Gibraltar	9 701	3 798	6 699
Keflavik	7 164	4 263	5 343
Helsinki	6 289	1 917	3 388
La Reunion	11 222	7 535	8 850
Azores	9 985	5 357	7 685
Payerne	8 185	2 446	5 141
Camborne	8 262	3 300	5 581

4 Typical radionavigation station parameters

The following section outlines various technical parameters of the radionavigation service.

4.1 RNAV transmitter characteristics

The parameters in Table 4 were used as being representative of a typical RNAV transmitter.

TABLE 4
Radionavigation stations parameters

Name of transmitting station	Occupied bandwidth (Hz)	Transmitting centre frequency (kHz)	Antenna input power (dBW)
Komsomolsk Na Amure	100, 200	11.905, 12.500, 12.649, 13.281, 14.881, 15.625	57
Krasnodar	100, 200	11.905, 12.500, 12.649, 13.281, 14.881, 15.625	57
Novosibirsk	100, 200	11.905, 12.500, 12.649, 13.281, 14.881, 15.625	57

4.2 RNAV antenna efficiency

The efficiency of a typical RNAV transmitting antenna at these frequencies is not known and is likely to be very small. Work by Raghuram *et al.* [1974], cites efficiencies of VLF transmitting antennas as low as 6 to 8% over a 3 000 m thick ice sheet, whereas over a conducting earth it is as low as 0.1% [1]. However references in declassified documents on the historical Omega system [2] provides efficiency values of the order of 10%. For these studies the radionavigation services have an assumed radiated power of 40 dBW. For radiated powers greater than 40 dBW, the required separation distances between stations shown in this study would be greater.

5 Typical ATD station parameters

Typical ATD station parameters are presented in Table 5.

TABLE 5
Typical ATD system parameters

Technical characteristics of the ATD system	
Receiver centre frequency	9.766 kHz
Receiver (sensor unit) amplifier gain	12 dB if switched on by control software (normally the case) otherwise zero [3]
Measurement bandwidth	3 kHz
Total “pass-band”	6.87 to 20.6 kHz
Antenna type and directivity	2 m vertical polarization, omnidirectional whip
Software filter	Broad-band high-pass filter (3 dB at 2.0 kHz), cascaded with low-pass filter (0.28 dB pass-band limit at 17.75 kHz)
Software narrow-band pass filter	3 dB bandwidth 2.5 kHz 10 dB bandwidth 4.3 kHz 20 dB bandwidth is 5.7 kHz
Typical receiver noise floor	−70.4 dBm in a 5 kHz reference bandwidth

6 Considerations of atmospheric noise

Recommendation ITU-R P.372-9 gives typical values for radio noise between 0.1 Hz and 100 GHz. Noting that in case of a ATD receiver the antenna is a 2 m monopole, used at frequencies where λ equates to between 25 to 38 km; equation (7) in this recommendation gives a suitable method to use to approximate levels of atmospheric noise at the input to this type of antenna.

Equation (7) provides the method, for a short ($h \ll \lambda$) vertical monopole, to calculate the r.m.s. vertical field-strength value of atmospheric noise above a perfect ground plane.

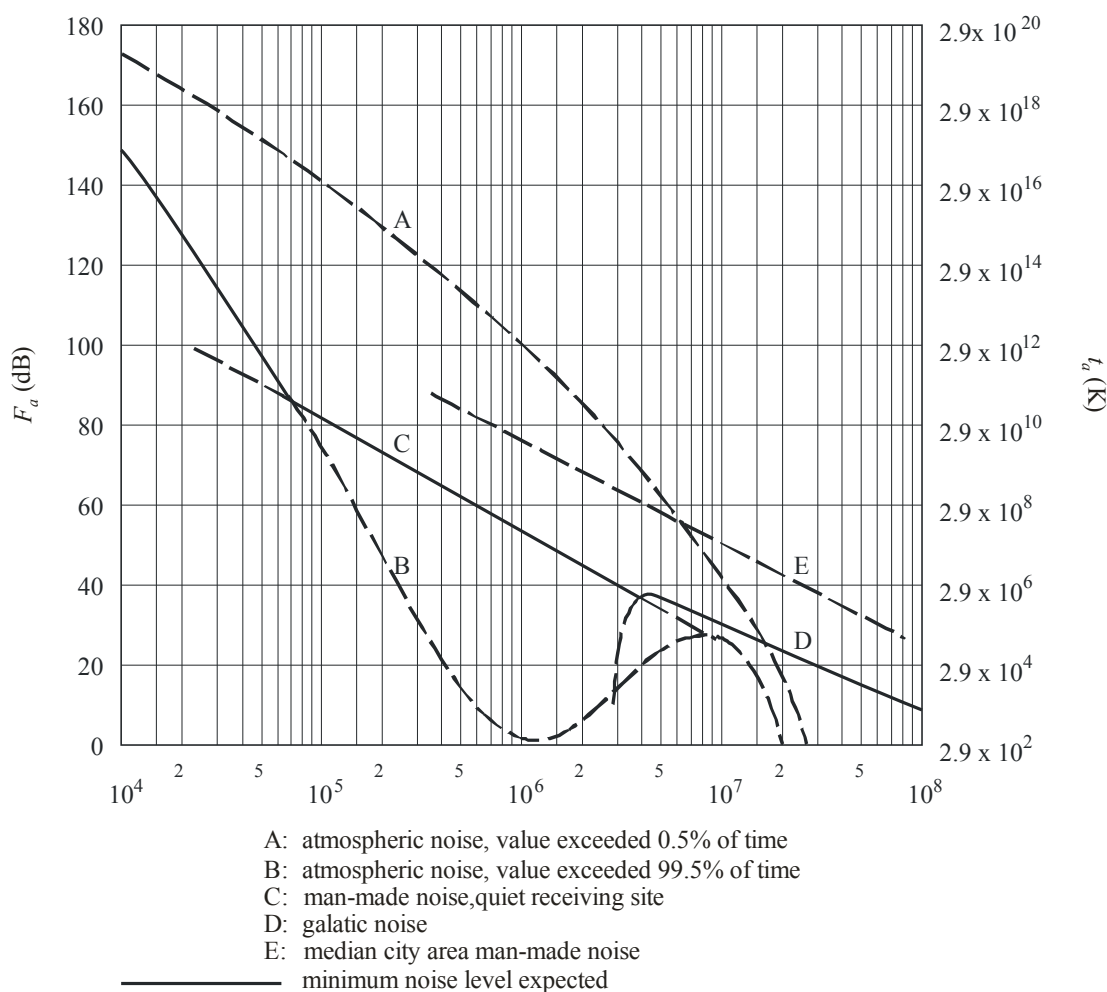
The equation is given by:

$$E_n = F_a + 20 \log f_{\text{MHz}} + B - 95.5 \text{ dB}(\mu\text{V/m})$$

where:

- E_n : field-strength in bandwidth b
- f_{MHz} : centre frequency (MHz)
- B : bandwidth of receiver
- F_a : is the indicative value of atmospheric noise and is taken from Fig. 2.

FIGURE 2
 F_a versus frequency (10^4 to 10^8 Hz)



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While Fig. 2 gives indicative values of atmospheric noise for 0.5% and 95% of the time, it is generalized and gives no information to their range of validity, especially regarding variances over geographical location, time and season. The same recommendation gives maps identifying expected values of F_{am} (median values of man-made noise power) (dB above KT_0b at 1 MHz, Figs 15a-38a) in different regions. In addition, it provides variation curves to assess the equivalent atmospheric noise values at other frequencies, in this case 10 kHz.

For example the values of F_{am} in wintertime over Europe range from 165 dB (04:00-08:00 h) to 151 dB (08:00-12:00 h). During spring time values of F_{am} are relatively constant until about 1 600 h where levels rise from about 155 dB to 162 dB.

The values of F_{am} for Hawaii correspond well with the values for Europe (within ± 5 dB).

In contrast, the values of F_{am} around Central Africa, Northern Australia and Malaysia show consistently higher values than those shown in Europe. During the period 16:00-20:00 h in the Summertime, F_{am} is as high as 172 dB, which is 10 dB higher than the highest values seen in Europe throughout the year.

Considering that the ATD sensor is limited by these variances in atmospheric noise, system performance is directly linked to the level of the atmospheric noise, therefore noise limited.

For example during times of high atmospheric noise levels the ATD system would not suffer performance limitations from interference from radionavigation service to the same degree as at those times or areas where atmospheric noise levels decreased by say 20 dB. This is point is especially important when the Earth-ionosphere wave guide effects on the interfering path do not vary to the same degree.

Considering that most ATD sensors are currently located in Europe and a high proportion of the origin of paths discussed in later sections within this paper are from Hawaii, the F_a value used in this study is 151 dB.

Using this assumption the atmospheric noise (E_n) at 9.766 kHz in a reference bandwidth of 3 kHz can be calculated as follows:

$$E_n = 151 + 20 \log (9\,766 \times 10^{-3}) + 10 \log (3\,000) - 95.5 \text{ dB}(\mu\text{V/m})$$

$$E_n = 50 \text{ dB}(\mu\text{V/m})$$

This value also corresponds to findings shown in ERC Report 069, which concludes that the levels of atmospheric noise field-strength levels at the 10 kHz range between 50-58 dB($\mu\text{V/m}$) over a typical year within the European area.

Although 50 dB($\mu\text{V/m}$) of atmospheric noise is the integrated effect of lightning strikes around the globe, and if localized lightning strikes were to occur the level would much higher; in this study 50 dB($\mu\text{V/m}$) is taken to be the minimum wanted signal.

7 Interference mitigation

Notch filters are provided for removing the effects of interfering VLF radio transmissions primarily from sources other than the radionavigation services, which could in principle be highly coherent between outstations and could give rise to errors.

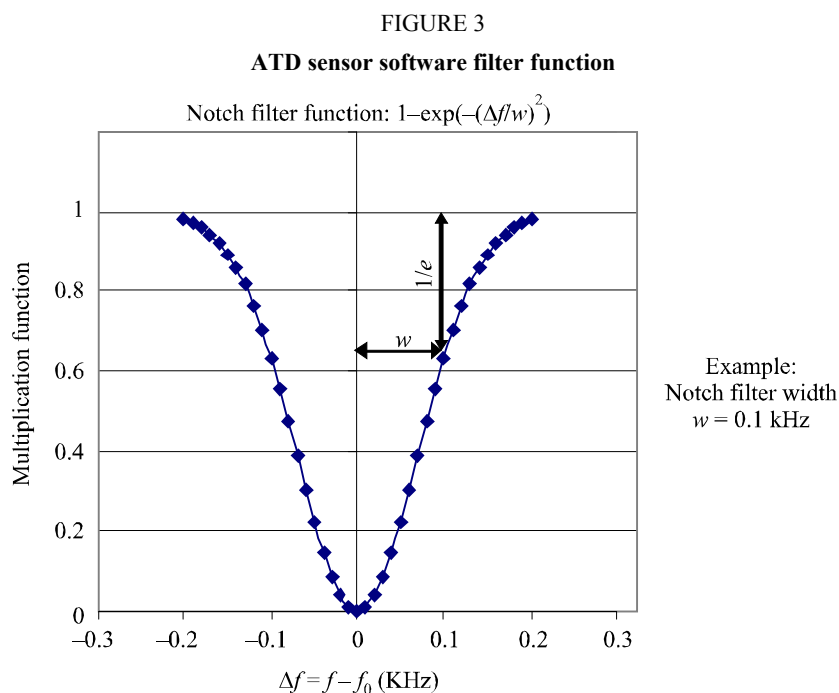
The software notch filter function has the form:

$$1 - \exp(-(\Delta f/w)^2)$$

as indicated in Fig. 3 where:

- f_0 : the nominal frequency of the notch
- Δf : the displacement of the frequency f from f_0
- w : its width.

At the notch filter nominal frequency the signal is zeroed, but the reduction in signal becomes negligible at twice the notch width.



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Considering the above notch filter function the typical attenuation that can be achieved for a 0.02 kHz and 0.2 kHz filter widths are 6 dB and 26 dB respectively.

The set up of notch filters of the same order can be seen in Fig. 4. In this example the measurement frequency is 13.766 kHz, with notch filters at 11.90 kHz (0.02 kHz), 12.65 kHz (0.02 kHz) and 16.4 kHz (0.2 kHz) (although these were not enabled when the screen shot was taken).

8 ATD receiver sensitivity and maximum permissible interference

Recommendation ITU-R RS.1881 specifies the minimum C/I values in respect to various frequency offsets from the ATD detection centre frequency. The following sharing study used the following assumptions:

- 50 dB(μ V/m) as a minimum carrier level;
- Notch filtering implemented at 1, 2, 3, 4 and 5 kHz separation from measurement centre frequency, (notch filters of 0.02 kHz, 0.2 kHz, 0.2 kHz, 0.2 kHz and 0.2 kHz respectively).

From these assumptions the values for maximum field-strength of “I” can be derived for pulsed types of interferer. These are shown in Table 6.