REPORT ITU-R M.2013

WIND PROFILER RADARS

(1997)

1 General subject matter

1.1 Introduction

Wind profiler radars are radio systems which can be very helpful in weather forecasting applications. To be able to make use of the benefits of wind profiler radars, suitable radio frequency bands need to be identified for the accommodation of this type of system.

One must note the existence of acoustic wind profilers (Doppler SODARs). They can be used to complement certain wind profiler radar measurements at very low altitudes. However, we stress that Doppler SODARs cannot be used as a substitute for wind profiler radars.

On the one hand, radar systems for weather forecasting purposes are to be accommodated in the frequency allocations of the radiolocation service and/or the meteorological aids service. Existing uses in these bands need to be protected and compatibility with the services in the adjacent bands has to be assured. On the other hand, accommodation in the frequency bands of other radio services could be considered, if this is acceptable from a frequency-sharing point of view.

For the identification of the various compatibility and/or sharing options, a clear understanding of the concept of wind profiler radar systems and their behaviour in the electromagnetic environment is needed.

In the following paragraphs the need for wind profiler radars will be touched upon and a general system description will be given including the typical electromagnetic behaviour.

1.2 User requirements for wind profiler radar data

The development of weather forecasting presently requires frequent, closely spaced and high quality wind data with improved accuracy from near the Earth’s surface to high in the atmosphere. Wind data based principally on balloon borne instruments, satellite measurements and automated aircraft reporting systems are insufficient to satisfy the needs of the increasingly high resolution atmospheric computer models as well as those on man-machine interactive forecasting systems. Without substantial increases in high resolution wind data, the capacity of these new models and interactive systems being deployed later this decade to improve weather forecasts and severe weather warnings will be greatly limited.

Planetary numerical models of the atmosphere which produce three to ten day forecasts require upper air data from extensive areas of the globe. Especially in remote areas, wind profiler radars operating unattended may offer a means of obtaining essential high altitude data for these models from data sparse areas.

Numerical models for forecasts from 3 to 48 h covering a continent or smaller area require data from a large vertical extent of the atmosphere, typically from 200 m to 18 km, with vertical resolution of approximately 250 m depending on the application. The time resolution presently needed is for hourly data.

For very short-term weather forecasting, air pollution monitoring, wind field analyses and forecasts of toxic plume trajectories resulting from chemical or nuclear incidents, severe weather warnings for aviation, meteorological observations, airport operations and public protection, meteorologists need wind information with a very high temporal and spatial resolution, mainly in the lower atmosphere. The requirements are for continuous data acquisition, between the ground and 5 km, with a desirable resolution sometimes as low as 30 m. Measurements will usually be made in populated areas.

Wind profiler radars also play an important role in experimental atmospheric research. Their ability to measure wind with a high temporal and spatial resolution makes them very well suited for the experimental verification of models, for boundary layer research and for the investigation of processes that are important for understanding the atmosphere, including climate evolution.

At present meteorological organizations use balloon borne systems to measure profiles of wind, temperature and humidity from the ground to high in the atmosphere. While current wind profiler radars do not operationally measure all of these parameters, they do have several advantages in comparison to the balloon based systems in meeting the above-mentioned requirements:

– they sample winds nearly continuously;

– the winds are measured almost directly above the site;

– the vertical air velocity can be measured;

– they provide the temporal and spatial density soundings needed to compute derived fields in a much more timely manner;

– the cost per observation is lower;

– they operate unattended in nearly all weather conditions.

In addition, it has been demonstrated that wind profiler radars can be adapted to measure temperature profiles when they are used in conjunction with a radio-acoustic sounding system (RASS). This opens the possibility to obtain denser and higher quality temperature profiles compared to present measurement techniques such as balloon tracking. No other measurement technique will present comparable advantages in the near future, including satellite borne sensors.

The World Meteorological Organization has expressed the need to operate such radars as a matter of urgency, due to the necessity of better monitoring and forecasting of the Earth’s atmosphere. A standardization of operating frequency bands is most important for the weather services in order to build an operational network in a practical and cost-effective manner.

1.3 System concept of wind profiler radars

Wind profiler radars are vertically directed pulsed Doppler radars capable of analysing the back-scattered signals to determine the velocity of air along the beams. By steering the beams typically 15° from zenith, the horizontal and vertical components of the air motion can be obtained.

Wind profiler radars depend on signals scattered from gradients in the radio refractive index associated with turbulent eddies with scales of one-half the radar wavelength (Bragg resonance). Hydrometeor scattering may also contribute or even dominate the returned signals, depending on the radar operating frequency. The goal of detecting the very weak clear air signals dictates the use of long coherent dwell times, low-noise system design, low antenna side lobes, and careful attention to siting, and potential interference.

A related development, the RASS provides profiles of temperature, typically with no alteration of the radio emission characteristics of the wind profiler radar. The propagation velocity of a Bragg-matched acoustic signal, which is related to the air temperature, is measured by the wind profiler radar using slightly different Doppler processing.

The nature of the scattering mechanism requires wind profiler radars to function between 40 and 1 400 MHz. As frequency increases over 1 300 MHz, performance of the wind profiler radar decreases significantly. The choice of operating frequency is influenced by the required altitude coverage and resolution.

1.4 Radiation aspects of wind profiler radar systems

In practice, systems are built for three frequency bands, i.e. around 50 MHz, 400 MHz, and 1 000 MHz, and these systems typically operate in two modes (see Note 1) which trade height coverage for resolution. Table 1 lists the range of characteristics of wind profiler radars in these three bands:

NOTE 1 – Low mode means shorter pulse, lower altitude; high mode means longer pulse, higher altitude.

TABLE 1

Range of operational wind profiler radars characteristics

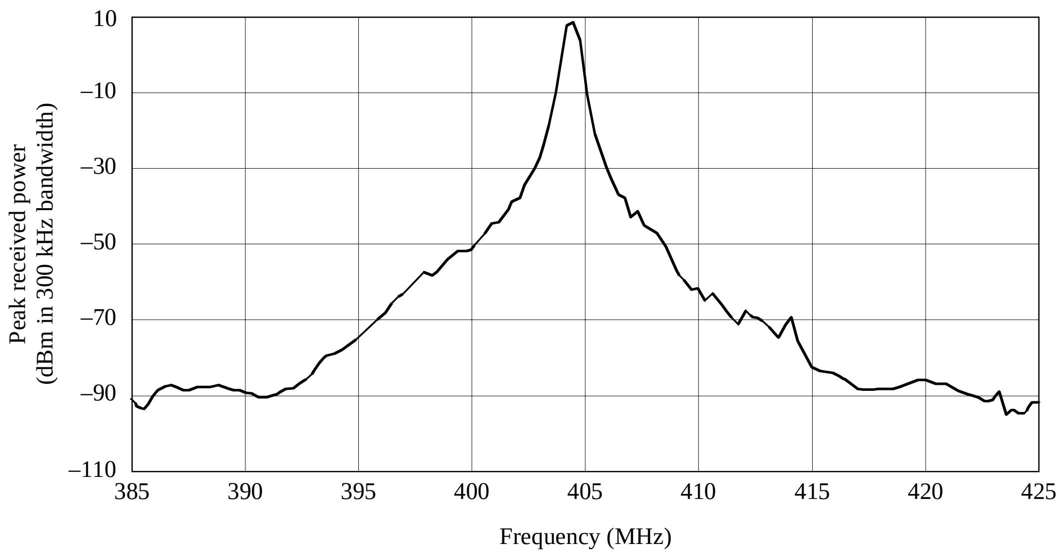
	50 MHz	400 MHz	1 000 MHz
Height range (km)	1-24	0.5-16	0.5-3
Height resolution (m)	150-1 500	150-1 200	30-150
Antenna type	Yagi, coaxial, co-linear	Yagi, coaxial, co-linear, co-linear	dish, patch co-linear
Antenna size (m^2)	2 500-10 000	30-150	3-15
Peak power (kW)	5-60	5-50	0.5-5
Mean power (kW)	0.5-5	0.2-2.0	0.05-0.5
Necessary bandwidth (MHz)	0.2-2.2	0.3-2.2	0.7-7.3

1.4.1 Harmonization of operating frequencies

Global harmonization of wind profiler radar operational frequencies and identification of spectrum by a world radiocommunication conference is most important. This will enable cost-effective development and exploitation of wind profiler radars. Wind profiler radars are operated as pulse-modulated Doppler radars or in frequency modulated-CW-mode. FM CW-mode radars were not considered further in this report because of lack of technical standard. Examples of spectrum produced by a pulse-modulated Doppler radar is shown in Fig. 1.

FIGURE 1

Spectrum characteristic of a pulse-modulated Doppler radar



Pulse width: 1.67 μs
Pulse repetition frequency: 10 kHz

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Based on discussions with manufacturers, wind profiler radars (see Note 1) can be designed to operate on assigned frequencies in a range up to ±1 per cent.

NOTE 1 – For example, the National Telecommunications and Information Administration (NTIA/USA) – "Manual of Regulations and Procedures for Federal Radio Frequency Management".

To accomplish this, small compromises would have to be made in the design of the RF power transmitter, antenna, circulator, and receiver noise figure. These would not be expected to degrade performance by more than 1 dB, an amount which could easily be compensated by a small increase in radiated power.

1.4.2 Antenna pattern

The desired signal being a reflection from clear air is very weak. This requires both extreme sensitivity in the wind profiler radar receiver and a vertically directed antenna with low amplitude side lobes. The antenna pattern, especially at large off-axis angles from main beam, is important in analysing potential interference.

As measurements for a 400 MHz wind profiler radar in Switzerland have shown, siting the profiler antenna in a sufficiently deep topographical depression can reduce most low-elevation side lobes by up to 20 dB. Terrain shielding is also effective for 50 MHz wind profiler radars as experience in Japan and Germany has shown. Investigations in Germany show that a specially designed fence around a profiler antenna can improve the low-angle side-lobe suppression by 10 dB to 15 dB.

1.4.3 Polarization

The polarization of signals received near the ground from a wind profiler radar changes randomly as a result of the scattering process. Similarly, the polarization of signals received directly from a side lobe is also likely to be random. The mean contribution of polarization decoupling to an improvement of sharing conditions is, therefore, only minimal (e.g. 3 dB).

1.4.4 Occupied bandwidth

For the efficient use of the limited radio spectrum resource, all efforts must be made to reduce the occupied bandwidth as well as unwanted emissions to a minimum.

The spectrum produced by pulse-modulated emissions is mainly determined by the shape of the pulses, the choice of the transmitter chain and the output filtering employed. Control of the spectrum can be achieved by appropriate pulse shaping, phase modulation and amplifier linearity.

Measurements accomplished in Germany with a 50 MHz wind profiler radar in this respect have shown that pulse shaping reduces the occupied bandwidth by a factor up to five compared to the bandwidth of rectangular pulses.

It should be noted that pulse shaping produces, as a side effect, a reduction of average transmitter power and a reduction of the effective range.

With reference to the 99% bandwidth (see Radio Regulations (RR) No. S1.153) of the radars in Fig. 1, the spectrum represents good technical achievement at this time.

Due to the fact that the bandwidth of a frequency modulated emission largely depends on the frequency deviation, it should be reduced as far as possible with regard to technical and operational/functional aspects of the spectrum.

In this study it is assumed that the occupied bandwidth of a wind profiler radar completely falls within a proposed candidate band.

1.5 Sharing considerations between wind profiler radars and other systems in various services

It may be possible to use bands other than those as identified in this report but such use must be preceded by studies which show compatibility.

1.5.1 Land mobile service

Sharing between wind profiler radars and the land mobile service is possible with proper frequency/distance (F/D) separation. Land mobile operations are mostly concentrated in urban areas. In some countries wind profiler radars may be located in remote areas. This will enhance sharing possibilities except in densely populated countries. Two cases must be considered concerning sharing with wind profiler radars. The two cases are sharing with base stations and sharing with vehicular and portable stations. Sharing with base stations is easier since they operate at known specific locations, thus proper distance separation can be maintained. Vehicular and portable stations, however, operate intermittently throughout the entire area covered by the base station.

1.5.2 Aeronautical services

In general, sharing with airborne systems requires large F/D separation and as a result sharing may be difficult. In addition, harmful interference to aircraft must be avoided in bands which provide critical communication such as aeronautical radionavigation.

An aircraft flying close to the wind profiler radar may suffer harmful interference and may also cause strong reflections back to the wind profiler radar that will disrupt wind data for that length of time. Thus, the location of wind profiler radars intended for strictly meteorological use, should avoid the flight paths of aircraft. On the other hand, 1 000 MHz wind profiler radars might be used in airport areas for measuring winds. In this case, the benefit of the observation may outweigh the temporary disturbance by aircraft.

1.5.3 Satellite and space services

Sharing with satellite and space services requires large angular and frequency separation, and as a result sharing may be difficult. Usually satellite and space services receivers are very sensitive and may experience interference and overload from wind profiler radars depending on the position and antenna pattern. Wind profiler radars are also very sensitive, and may experience interference from satellite and space services. Harmful interference to safety-of-life satellite operation must be avoided.

1.5.4 Fixed service

Sharing between wind profiler radars and the fixed service is possible with proper F/D separation.

Fixed systems typically transmit point-to-point or point-to-multipoint over tropospheric propagation paths (including line-of-sight). Some fixed systems employ highly directional antennas. The transmission paths are well defined. Some fixed systems are transportable.

1.5.5 Radio astronomy service

Radio astronomy stations are receiving stations that listen for radio waves of cosmic origin. Radio astronomy bands are used internationally for various activities such as very long baseline interferometry and spectral line observations. Receivers used for radio astronomy are extremely sensitive and this service requires large frequency and/or distance separations from other services to preclude interference.

Furthermore, wind profiler radar users operating in bands adjacent to radio astronomy bands must ensure that harmful interference is not caused to radio astronomy. These bands should be avoided.

1.5.6 Meteorological aids service

This service is used worldwide for gathering meteorological data for weather prediction, severe storm warning and research. Data gathering systems include satellite imagery and radiosondes.

Tracking of balloons and telemetry from radiosondes may be accomplished in several ways. Therefore, the sharing criteria must be in accordance with the method used to receive wind data.

1.5.7 Radiodetermination service

Radiodetermination radar systems may be installed on land, ships or aircraft. Land-based radars are designed to operate at either permanent sites or temporary sites using transportable equipment. These radars generally scan in specific directions using directional antenna. Shipborne radars operate at sea, along coastal and inter-coastal waterways. These radars scan 360° in the horizontal plane. Airborne radars may be operated anywhere and need the greatest distance separation of the three installations depending on altitude. These radars have a variety of scanning characteristics. Radionavigation systems generally have a safety-of-life function, which may make frequency sharing not practical.

1.5.8 Broadcasting service (television)

Compatibility between wind profiler radars and television broadcasting services must take into account the following factors:

– co-channel, overlapping channel and out-of-channel protection ratios for the different concerned television standards;

– non-linear effects;

– radar site conditions including site screening and side-lobe attenuation;

– propagation, including environmental and topographical factors;

– protection of wind profiler radar signals in a highly saturated spectrum with high power emissions;

– protection of new digital broadcasting systems under development in some countries.

1.5.9 Amateur service

As with other terrestrial services, the amateur service may be able to share with wind profiler radars under certain conditions. The primary consideration is the maintenance of frequency and/or distance separations sufficient to avoid mutual interference. However, the weak-signal segments of these bands are used for experimentation with non-line-of-sight and anomalous propagation modes. These segments should be noise limited, not interference limited. Operation of wind profiler radars should be avoided in the weak-signal segments of the amateur service.

2 Bands around 50 MHz

2.1 Introduction

2.1.1 Use of the bands around 50 MHz

In view of the physics involved, for measurements above 20 km, only the 50 MHz band can be used.

The bands around 50 MHz are ideally suited for high altitude measurements. There are two reasons for this. First, high altitude measurements generally require low resolution. Second, technology is relatively inexpensive: transistors are readily available; workmanship does not require a high degree of precision. The antenna array, however, requires significant real estate and consequently low altitude coverage is hindered.

2.1.2 Characteristics of the 50 MHz wind profiler radar

The portion of the VHF band used by wind profiler radars throughout the world covers 40 MHz to 80 MHz. Typical wind profiler radar characteristics are listed in §§ 1.4 and 1.4.2.

2.2 Compatibility

This section describes the compatibility between wind profiler radars and other radio systems.

2.2.1 Introduction

Radiolocation and meteorological aids services are not allocated in most countries in the frequency range 40-60 MHz. The band 47-68 MHz is allocated to the broadcasting service in Region 1. The band 50-54 MHz is allocated to the amateur service in Regions 2 and 3 and in some part of this band in Region 1.

In Japan, the broadcasting service is not in use around 50 MHz. The mobile and/or fixed services are allocated in the band 54-60 MHz and these services are used for disaster communications.

In France, studies have been carried out to determine the sharing criteria in the broadcasting band between wind profiler radars and the television service around 50 MHz. France also uses systems ancillary to broadcasting in this band, such as cordless microphones, outside broadcasting or electronic news gathering links.

The various bands within the 40-80 MHz frequency range are allocated to different services, sometimes by region or country. Portions of some bands are allocated to services by RR footnotes. These services have different status (for example, primary or secondary) depending on the band, region or country. These services are:

- aeronautical radionavigation;
- amateur;
- broadcasting (including applications ancillary to broadcasting);
- fixed (data and communication links such as point-to-point and meteor-burst);
- ISM (industrial, scientific and medical) applications;
- mobile (including applications ancillary to the mobile service);
- radio astronomy;
- radiolocation;
- space research.

2.2.2 Compatibility conditions

The compatibility conditions should be adapted to the services concerned. Any operation of wind profiler radars in the bands around 50 MHz should take into consideration ionospheric and tropospheric propagation modes that could result in wind profiler radars interfering with radiocommunication.

2.2.2.1 Protection of the broadcasting service

In order to ensure the protection of the broadcasting service, the following factors must be determined.

2.2.2.1.1 Protection ratios in co-channel, overlapping channel and out-of-channel situation

In an overlapping channel situation, gaps between vision and sound subcarriers may reduce the protection ratio. The portion of the gaps is system-dependent. These protection ratios are determined by laboratory measurements using the radar output. Figures were obtained by experiments using a broadcast quality L/SECAM television signal. The picture was a reference colour bars pattern. The sound was modulated with a 1 kHz tone. The radar which was simulated was the routine-meteorology 50 MHz wind profiler radar being developed by the French Meteorological Office. The pulse width was 6 μs. The radar was simulated by a signal generator followed by a bandpass filter, with a frequency response of ±1 MHz at 10 dB and ±3 MHz at 50 dB.

Several TV sets, representative of those currently in use in France have been used.

In overlapping situations, the protection ratios obtained ranged from 27.9 dB to 55 dB. Protection ratios obtained seem in good accordance with Recommendation ITU-R BT.655. These results have to be confirmed by measurements with a real radar. This range may not be the same for a different television system.

Recent tests with TV sets in North America (M/NTSC) indicate that use of extensive comb filtering of frequency lines between the video carrier and the colour subcarrier of newer television sets, do not yield the traditional "W" curve of the in-band protection ratios. This curve (Recommendation ITU-R BT.655) has been used for many years to determine the required protection ratio for the operation of carriers within the TV channel. Laboratory tests have indeed shown that the protection ratios are as restrictive as the case of overlapping carriers (e.g. a desired-to-undesired signal ratio of about 50 dB).

2.2.2.1.2 Non-linear effects

The non-linear effects are determined by means of protection ratios with a radar with a wide frequency separation from the wanted television channel and using several receivers representative of modern design, further studies may be necessary on the non-linear effects which may occur.

2.2.2.1.3 Harmonic radiation

The harmonic radiation of the radar may fall within the range of vulnerable services. According to the local situation, the level of this radiation should be measured and if necessary reduced as much as possible by using a device such as a harmonic filter.

2.2.2.1.4 Radar site conditions

The vertical radiation pattern of the radar antenna exhibits a degree of attenuation of the side lobes relative to the main beam. Site shielding may enhance the attenuation at ground level.

In rural areas, high gain antennas and signal preamplifiers are used to receive the broadcasting service, and should be taken into account when determining the sensitivity of television receiving systems. Side-lobe attenuation may not be sufficient to ensure interference-free television reception in rural locations that have insufficient frequency/distance separation from wind profiler radars.

In hilly areas, a television reception site may exist with a certain elevation angle for which the corresponding side-lobe attenuation on the wind profiler radar is not sufficient, hence causing interference to the broadcasting reception. Experiments on the routine meteorology wind profiler radar mentioned above showed that received power may increase by 20 dB for 2° of elevation angle, and 52 dB for 15° to 20°. Terrain profile must be considered when studying sharing.

In mountainous areas, the shielding effect decreases the wind profiler radar interference signal, but this effect also applies to the received broadcasting signals. Care must be taken to protect the television service in this case.

2.2.2.1.5 Propagation

Detailed propagation data for calculating the field strength of the wind profiler radar and broadcasting station are given in Recommendation ITU-R P.370. Corrections should be used for low radar antenna height, typically 1 m to 3 m above ground level. Field measurements are recommended to complete the study.

2.2.2.1.6 Required separation distance

A geographical separation distance of the order of 100-200 km may be necessary to achieve compatibility between wind profiler radars and the nearest broadcast receiver when they operate within the same channel.

In the case of out-of-channel operation, the geographical separation distance may be significantly reduced.

2.2.2.2 Protection of wind profiler radars from the broadcasting service

In France, a television transmitter tuned to the wind profiler radar frequency (45 MHz), has been installed on four successive locations (at a height of 30 m above the ground) at a distance of 10 km from the radar site.

The radar signal proved to be disturbed by the television transmitter at 45 MHz as soon as the effective radiated power (e.r.p.) was higher than 0.1 W at 10 km.

2.2.2.3 Optimization techniques

For a specifically designed system, allowing better attenuation, the maximum tolerable field strength can be 10 dB to 20 dB higher. This can be achieved through antenna array optimization techniques (weighting) which minimize the level of the side lobes at low elevation angles.

The choice of the operating frequency of the wind profiler radar can be adjusted in order to fit in the gap between the television carriers.

In addition, when installing a wind profiler radar at a given location, it is possible to use several techniques minimizing the interferences from television transmitters:

– the tilt of the wind profiler radar beams should not be oriented in the direction of television transmitters;

– the natural (valley) or artificial (fences) shields can lower the electric field strength received from the television transmitter through the side lobes of the antenna radiation pattern.

2.2.2.4 Other services

For the mobile service, for example, the compatibility becomes difficult for the reason that the position of the mobile is generally not known. Bands to consider carefully are radio amateur bands, radio astronomy observations and aeronautical radionavigation for compatibility. For a mobile base station, geographic distance separation up to 200 km is needed with mountains shielding effect for compatibility. Wind profiler radar operations on frequencies around 49 MHz may interfere with weak-signal amateur operation in the band 50-51.1 MHz if the wind profiler radar sidebands are not sufficiently attenuated.

2.3 Conclusions for the bands around 50 MHz

The frequency range 40-80 MHz is generally suitable from a frequency sharing point of view for the operation of wind profiler radars, provided that the following conditions are satisfied:

– Wind profiler radar density is relatively low.

– Broadcasting station density is relatively low.

– Sharing arrangements are made with all the services operating in these ranges. These sharing arrangements should take into account the protection of any new digital broadcasting system being considered.

3 Bands around 400 MHz

3.1 Introduction

Wind profiler radars used for measurements on the so-called mesoscale (spacing around 100 km) need to operate around 400 MHz in order to fulfil the needs with respect to vertical range and resolution; they are commonly called 400 MHz wind profiler radars. However, any frequency between 300 MHz and 500 MHz is adequately scattered by atmospheric motion and can thus provide wind profiles on the mesoscale. At this point, it should be recalled that 400 MHz wind profiler radars are regarded as cost effective and convenient instruments for meteorological analyses and forecasts.

As presently envisaged, wind profiler radars will be located in either remote or urban areas. Methods to enhance sharing may be feasible. Although only few extensive studies have been conducted, it is clear that compatibility can be enhanced by appropriate siting, fences, berms, antenna nulling, modulation techniques and coding. Other factors such as the technical and operational characteristics of the wind profiler radar and other systems, sharing criteria, and their relative locations should also be considered.

To minimize cost, the number of frequencies selected for wind profiler radar operation in this range should be kept to a minimum.

Consequently, a review of the entire range from 300 MHz to 500 MHz for candidate and non-candidate bands for the operation of wind profiler radars seems appropriate.

3.2 Comments on different bands between 300 MHz and 500 MHz

3.2.1 General considerations related to mobile services

Physical separation typically up to 75 km may be needed for co-channel operation with land mobile base stations for maximum wind profiler radar transmitter power (40 kW) and with mountain shielding effects. These distances can be further reduced by synthetic attenuators such as berms, fences, etc.

3.2.2 300 to 399 MHz

This band is allocated to the fixed, radio astronomy, aeronautical radionavigation and mobile services. The entire range is heavily used by most nations for extensive radio-relay, air-ground-air, satellite, air traffic control, and other operations. Congestion and the constantly increasing need for more channels within this band have resulted in a reduction of the channel from bandwidths 100 kHz to 50 kHz, and most recently to 25 kHz. The congestion of this band and the nature of the numerous stations operated therein (particularly the large number of aeronautical mobile stations spread over the entire range) makes it difficult to share with wind profiler radars.

3.2.3 400 to 410 MHz

As a result of Recommendation 621 (WARC-92) of the World Administrative Radio Conference for Dealing with Frequency Allocations in Certains Parts of the Spectrum (Malaga-Torremolinos, 1992), the meteorological aids band has been determined as unsuitable for wind profiler operation. In addition to compatibility problems with the international satellite system for search and rescue (COSPAS-SARSAT) (see below), interference with space data collection systems would occur.

The 406 to 410 MHz range is allocated to the radio astronomy service as well as fixed and mobile services. Again, operation of wind profiler radars in this range is prevented by the need to avoid interference to COSPAS-SARSAT.

In the 406.0 to 406.1 MHz band, the COSPAS-SARSAT system – a low-orbiting satellite system providing worldwide distress alerting and location capabilities using high sensitivity spacecraft receivers – is operated. The SARSAT space component uses three near-polar meteorological satellites of the Tiros-N type and one geostationary satellite of the GOES-series; the COSPAS space component uses three radio navigation satellites of the Nadezhda type. This safety-of-life system receives distress messages from low-power emergency beacons. If wind profiler radars transmit high power pulses vertically in the same range of frequencies, these signals will interfere with distress signals and/or saturate the high-sensitivity receivers.

The frequency separation value to preclude interference from wind profiler radars into the COSPAS-SARSAT system was determined from the receiver characteristics and known radar emission spectra. Depending on assumptions, the frequency separation calculated range from a minimum of 5 MHz to 24 MHz for worst-case assumptions.

By shutting down the wind profiler radar when a satellite of the COSPAS-SARSAT system passes overhead, compatibility can be achieved (this method is presently used in the demonstration network consisting of about 30 wind profiler radars operated at 404 MHz in the central United States of America). However, apart from the fact that other sharing problems in this frequency range would not be solved, this method is considered not operationally practicable with hundreds or even thousands of radars deployed worldwide. At any rate, the international COSPAS-SARSAT system has been operational since 1985 and has already contributed to saving thousands of people; its proper operation must not be endangered in any way.

As a result, administrations must not authorize any additional wind profiler assignments in the band 400 to 410 MHz. As a temporary measure, administrations having existing wind profiler operations in the 400 to 410 MHz band should protect the COSPAS-SARSAT system by using techniques such as inhibiting the profiler transmission as the satellite passes overhead. It is noted that several cases of interference from non-network wind profiler operations have been reported resulting from human error (e.g. improper satellite schedule of passes being placed into the computer for scheduling shutdown).

The non-availability of this band to the meteorological wind profiler applications justifies the urgency to determine another frequency band in the 400 MHz range for this application.

3.2.4 410 to 420 MHz

This band is allocated to space research (space-to-space, extra-vehicular activities), as well as the fixed and mobile services. The fact that space research must be protected and due to the close frequency proximity to the COSPAS-SARSAT system, this band is considered a non-candidate.

3.2.5 420 to 430 MHz

This band is internationally allocated to the fixed and mobile (except aeronautical mobile) services on a primary basis and radiolocation on a secondary basis. It is used by high-power fixed, transportable, shipborne and airborne radars. Taking into account these radiolocation operations, the land mobile, and the fixed and amateur operations (existing in some countries), sharing with wind profiler radars in these bands seems possible. However, because the band is in close frequency proximity to the COSPAS-SARSAT system it is considered a non-candidate.

3.2.6 430 to 440 MHz

This band is allocated for radiolocation, amateur, space operations, amateur-satellite and aeronautical radiolocation services. Wind profiler radar sharing of the band 430-440 MHz is not possible because of worldwide amateur service weak signal operations in the band 431-433 MHz and amateur-satellite service operation in the band 435-438 MHz. In addition, the band 430-440 MHz is also shared with highly mobile radiolocation systems. As a result of these considerations, sharing of the 430-440 MHz band is considered a non-candidate.

3.2.7 440 to 450 MHz

This band is internationally allocated to the fixed and mobile (except aeronautical mobile) services on a primary basis and radiolocation on a secondary basis. It is used by high-power fixed, transportable, shipborne and airborne radars. Taking into account these radiolocation operations, the land mobile, and the fixed and amateur operations (existing in some countries), sharing with wind profiler radars in these bands may be possible. It should be observed, however, that wind profiler radars situated in close geographic proximity to locations performing operations under RR No. S5.286, may require a minimum frequency separation on the order of 1 MHz to preclude interactions. In order to identify the specific geographic and frequency separation required to preclude interaction, further analysis is needed.

With these considerations, this band is considered a candidate band for sharing with wind profiler radars.

3.2.8 450 to 470 MHz

This range is allocated on a worldwide basis to fixed and mobile services. The entire band is heavily used by a large number of mobile stations, such as paging systems without automatic acknowledgement and, in some administrations, new narrow-band and wideband mobile technology is likely to be introduced over the next 10 to 20 years. In addition, the 460 to 470 MHz band is allocated on a secondary basis to satellite services (space-to-Earth).

These considerations show that it may be difficult to accommodate wind profiler radars in this band.

3.2.9 470 to 500 MHz

The band 470-500 MHz is allocated to television broadcasting services on a worldwide basis. This band is extensively used by most of the countries around the world and studies are being carried on to implement more television stations using either existing technologies or future digital technologies. The access to the reception of broadcasting is widely open and the broadcasting coverage is wide. In many countries, thousands of transmitters are implemented to offer national and local television services.

Compatibility between wind profiler radars and television broadcasting services in the UHF band must take into account the technical factors mentioned in § 1.5.8.

A major problem with any radar – and a wind profiler radar is no exception – is the large required bandwidth. Under the condition that the separation areas between television stations operating in the same channel are large enough to allow the operation of a wind profiler in this channel and in this separation region, the bandwidth issue is no longer a major concern because the profiler could occupy practically the entire width of the TV channel.

Future development in some countries may lead to the introduction of terrestrial digital sound broadcasting and terrestrial digital television broadcasting in the broadcasting bands. However, the specific characteristics of digital television are unknown, and as a result it is not yet possible to predict the separation distances for future digital operations.

In addition, there will be a transition period where both analogue and digital television will be operating, thereby increasing the channel usage. As a result, there will be fewer sharing opportunities during this transition period.

Tests have been conducted regarding co-channel protection of analog G/PAL television systems from a wind profiler radar operating at 482 MHz. The results show a half-line frequency offset (appr. 7 800 Hz) between the wind profiler centre frequency and that of the video provide the best protection ratio values. A protection ratio value of 39 dB represents continuous interference from the profiler using half-line frequency offset. Additional improvements totalling 5 dB can be provided by precision frequency offset synchronization of the wind profiler operating frequency with that of the video and synchronization of the radar pulse repetition frequency and the video line frequency. If the half line offset frequency is not optimized, a degradation of the protection ratio value by 10 dB will result.

Coordination of operating parameters to each case can facilitate sharing between wind profiler radars and TV broadcasting.

When considering frequency sharing, the minimum required field strength for television signals is 53 dB(μV/m) as defined by Report ITU-R BT.409.

3.3 Harmonic radiation

The second harmonic radiation of the radar may fall within the range of mobile services in many countries.

The level of this radiation or interference should be measured and if necessary reduced as large as possible by appropriate measures (by using a device such as harmonic filter, by carefully selection of the frequencies or location of both systems in question, etc.).

3.4 Conclusions for the bands around 400 MHz

In the entire range 300-500 MHz, the frequency band 440-450 MHz and 470-500 MHz are considered as candidate bands. In the case of the 470-500 MHz band sharing arrangements should be made with existing and planned broadcasting services, including digital broadcasting service under consideration.

4 Bands around 1 000 MHz

4.1 User requirements and system characteristics

1 000 MHz wind profiler radars are ideally suited for the monitoring of the lower atmospheric layers. High resolution wind data between typically ground level and 5 km altitude are essential for local very short-term forecasting applications, warnings to the general public and aviation, air pollution monitoring and atmospheric research.

Air pollution transport models are utilized for forecasting local atmospheric dispersion of pollutants and in the case of chemical or nuclear incidents. These models need wind profiles at least every 10 min in the boundary layer, up to 3 km, with a vertical resolution down to 30 m.

For very short-term weather forecasts, and in particular for severe weather warnings for aviation, meteorologists need height profiles of the wind and wind shear information with high temporal and spatial resolution. Moreover, the lowest measuring level should be as close as possible to the ground.

In operational meteorology, low altitude wind profiler radars operating around 1 000 MHz are ideally suited for synoptic or mesoscale forecasting in complement to high altitude VHF profilers.

In atmospheric research, very high resolution wind data are needed in order to study the lower atmospheric layers. 1 000 MHz wind profiler radars can be used to estimate heat and momentum fluxes, which are important for the understanding of atmospheric processes.

1 000 MHz wind profiler radars can be equipped with acoustic systems in order to measure temperature profiles in the same ranges. This opens the possibility of a unique atmospheric monitoring system.

The above applications call for two types of wind profiler radars. The first one is a wind profiler radar providing typically data from 300 m up to 5 km with a range resolution of 150 m in order to complement the VHF wind data down to the boundary layer.

The other type of wind profiler radar for the other above-mentioned application is normally a stand-alone system.

The main characteristics of the two types of wind profiler radars would be mentioned in Table 2.

TABLE 2

	VHF complementary[(1)]	Stand-alone
Peak power (W)	4 000	1 000
Mean power (W)	80	50
Pulse width (µs)	1	0.3-10
Height resolution (m)	150	50-500
Maximum necessary bandwidth (MHz)	2	0.7-7.3
3 dB beam width (degrees)	6	4-10
Maximum side-lobe levels 0-5° elevation (dBi)	0	0

(1) A complementary system may be used in some cases as a stand-alone system.

1 000 MHz wind profiler radars can be produced relatively inexpensively compared to wind profilers at 50 MHz and 400 MHz. They are of smaller size and could be transportable. 1 000 MHz wind profiler radars may be used to determine wind conditions at airports.

4.2 Sharing/compatibility

The sharing of wind profiler radars with existing services within the band 864-1 427 MHz is described below.

4.2.1 Services in the 862-960 MHz band

This frequency band is intensively used by diverse services:

4.2.1.1 862-960 MHz in Region 1

In Europe much of the frequency band 864-960 MHz is already intensively used for land mobile services for both national and international systems. It is planned to introduce similar systems into the remainder of the band in the near future.

4.2.1.2 890-960 MHz in Regions 1 and 3

This band is allocated to broadcasting on a primary basis in Region 3 and in part of Region 1 (see RR No. S5.322).

4.2.1.3 900-960 MHz in Regions 1 and 3

This band is allocated to the fixed and mobile services on a primary basis. Considering the terrain shielding, typically up to 60 km of distance separation is needed for co-channel operation.

4.2.1.4 900-960 MHz in Region 2

Several countries use the band 902-928 MHz for high-power long-range fixed, airborne and shipboard search radars. Operation of wind profiler radars should be avoided in the weak-signal segments in the band 902-904 MHz allocated to the amateur service. The band 928-960 MHz is used by a number of high-density terrestrial services, including mobile and fixed systems.

4.2.1.5 Conclusions

Noting that:

a) in a large part of the world, the band 862-960 MHz is used by mobile services and considering the characteristics of this service, i.e. intensive use, and the limited possibilities to guaranty sufficient distance separation between the wind profiler radars and service users;

b) the required separation distances for fixed services;

c) the characteristics of the other services using the band,

it is concluded that there are no sharing opportunities for sharing the band with wind profiler radars except for part of the band between 904-928 MHz in parts of Region 2.

4.2.2 960-1 215 MHz: Compatibility with distance measuring equipment (DME) and TACAN

The DME system consists of an interrogator on board an aircraft and a transponder installed on the ground reference point. The interrogator transmits interrogation paired pulses to the transponder and receives reply paired pulses transmitted by the transponder. The interrogator calculates the slant range from the interrogator equipped aircraft to the transponder site. The TACAN system has the same distance measuring function as the DME system.

4.2.2.1 Compatibility with the ground transponders of DME

Taking into account the technical parameters of wind profilers and of the ground DME transponders as well as the design of the DME transponders which give some additional attenuation (75 dB) due to the specific coding of its pulse pairs, interference is due to the fact that the received power of the wind profilers increases the receiver noise level of the ground DME beacon and needs to be suppressed to an attenuation of 168 dB. This attenuation can be achieved by a distance in free space of 5 000 km at 1 200 MHz. Even though wind profilers are installed in mountainous areas where an attenuation of 20 dB can be achieved, a distance of 500 km is necessary to achieve the 148 dB attenuation.

4.2.2.2 Compatibility with the interrogator on board the aircraft

The receiver decoder of the interrogator on board the aircraft will receive an interfering signal 50 dB above the decoder rejection level of –78 dBW. This will cause severe interference to the receiver of the interrogator. It has been assumed that the interrogator of the aircraft is 1 000 m above and within the main beam of the wind profiler. Assume the radiated power of the main beam of the profiler to be 67 dBm and +30 dB of antenna gain.

As the spectrum of wind profiler radars is more than 1 MHz wide and as there is a DME channel every MHz, there is no possibility to achieve 50 dB attenuation if the wind profiler radars share the band of the DME/TACAN.

4.2.2.3 Result

A number of studies indicate that there is severe interference from wind profiler radars if they share the frequency band 960-1 215 MHz.

4.2.3 1 215-1 260 MHz: radionavigation-satellite service

Protection shall be provided to radionavigation-satellite service systems according to RR No. 953. This service is provided by the GPS L2 (GPS-global positioning system) signal (1 227.6 MHz with 20.46 MHz necessary bandwidth) and radionavigation satellite GLONASS-M system (before 2005: 1 246.0-1 256.5 ± 5.11 MHz; after 2005: 1 242.9-1 248.6 ± 5.11 MHz).

Field tests have demonstrated that operation of one VHF complementary wind profiler radar (low duty cycle) is compatible with certain GPS receivers (result independent of frequency). However, a 20 metre protection distance is needed to prevent front-end burn out. Furthermore, a preliminary study shows that the presence of six or more VHF complementary wind profiler radars within line of sight of the GPS receiver (without sufficient frequency separation) may preclude GPS L2 service.

Studies of interference produced to a global orbiting navigation satellite system (GLONASS) receiver by VHF complementary wind profiler radars operating at 1 238 MHz show that, for approximately a 20% bit loss, a distance separation of 105 km is required to allow wind profiler radar to operate while affording appropriate protection to the GLONASS system users.

Concerned administrations are invited to conduct further field tests in representative operational environments to determine sharing conditions. Compatibility with higher duty-cycle wind profiler radars requires further study.

4.2.4 1 240-1 300 MHz: Compatibility with the amateur services

There are several types of operations in the amateur services including repeaters and the amateur-satellite service. Compatibility between the wind profiler radar and these operations was studied.

Operation of wind profiler radars should be avoided in the band 1 295.8-1 297 MHz allocated to the amateur service corresponding to the weak-signal segment.

4.2.4.1 1 260-1 270 MHz: Compatibility with the amateur-satellite service

The amateur satellite within the wind profiler radar's main beam axis will receive the interference power up to 60 dB higher than the estimated interference threshold of –182 dBW.

Even when the satellite is at the direction of 60°-90° off axis of the main beam, it receives the interference power about 35 dB higher than –182 dBW from the wind profiler radar.

According to the above interference levels, the amateur satellite will be interfered by the wind profiler radar when it is within the line of sight of the wind profiler radar.

4.2.4.2 1 240-1 260 and 1 270-1 300 MHz: Compatibility with the terrestrial communication repeater station for amateur service

If the path length of wind profiler radar signal is 30 km, calculated interference power level is 82 dBm in free space propagation at the amateur service receiver input.

Taking into account the ratio of signal frequency bandwidth, actual interference level at the receiver input is about –100 dBm.

This level is 40 dB higher than the estimated interference threshold level of –170 dBW.

When wind profiler radars are installed in a mountainous area, then the interfering signal may be attenuated more than 20 dB.

4.2.4.3 Result

It is pointed out that the amateur services use various types of communications and consequently they may be subject to interference from wind profiler radars, in particular when the wind profiler radar frequency is the same as the one used with continuous wave at the satellite.

4.2.5 1 215-1 400 MHz: Compatibility with high power radars

This band is also allocated for radiolocation and is used by high-power fixed, airborne, shipboard and transportable radars. Sharing is possible with suitable frequency-distance separation in the following bands:

– 1 235-1 300 MHz in some countries;

– 1 300-1 350 MHz;

– 1 350-1 375 MHz in some countries.

4.2.6 1 215-1 300 MHz: Compatibility with Earth exploration-satellite (active) service

Synthetic aperture radars (SAR) on Earth exploration-satellites presently operate and will continue to operate throughout the band 1 215-1 300 MHz. Theoretical analyses have shown that sharing between one wind profiler radar and a SAR is possible. These studies have further shown that the co-frequency operation of a sufficient number of wind profiler radars and a SAR will unacceptably degrade the performance of the SAR. Sufficient centre frequency separation will be required in order to ensure compatible operation of wind profiler radars and active spaceborne sensors in this region of the spectrum.

Air route surveillance radars (ARSR) with higher isotropically radiated powers than the main beam powers of wind profiler radars have been in operation in this band for many years. Harmful interference to spaceborne sensor operations is usually not observed. However, degraded SAR performance is observed which may be attributed to ARSR transmissions.

4.2.7 1 400-1 427 MHz: Radio astronomy service

Protection of the radio astronomy service in accordance with RR No. S5.340 should be ensured.

4.3 Sharing conclusions

For very short-term weather forecasting, air pollution monitoring, emergency response to chemical or nuclear incidents and severe weather warnings for aviation and public protection, 1 000 MHz wind profiler radar can provide very important wind information with very high temporal and spatial resolutions.

Analysis of the aeronautical radionavigation band 960-1 215 MHz indicates that sharing with wind profiler radars is not possible.

The aeronautical radionavigation bands must be protected.

The amateur satellite service band 1 260-1 270 MHz and amateur service around frequency 1 296 MHz should be avoided.

The radionavigation satellite service must be protected globally from interference and operational constraints.

Typically up to 60 km of distance separation may be needed between a wind profiler radar and a land mobile base station for co-channel operation with mountain shielding effects.

Sharing with fixed high-power radars may be possible with suitable frequency-distance separations.

Sharing between one wind profiler radar and active spaceborne sensors is possible, but multiple co-frequency wind profiler radar operation with spaceborne sensors may not be possible.

Radio astronomy needs to be protected.

4.4 Conclusions for the bands around 1 000 MHz

Although a single frequency band is preferable for the wind profiler radar in terms of costs, it may be difficult to attain.

The candidate frequency bands are:

– 904-928 MHz;

– 1 235-1 241 MHz (with caution regarding radionavigation (see Note 1));

– 1 270-1 295 MHz;

– 1 300-1 375 MHz.

The above frequency bands may not be suitable for all regions.

As frequency increases over 1 300 MHz, performance of the wind profiler radar decreases significantly.

NOTE 1 – Wind profiler radar operation in this band may cause interference to the satellite radionavigation-satellite service receivers (see § 4.2.3). Sharing conditions should be determined on the basis of simulations and confirmed by field tests.