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RS Series: Remote sensing systems

Frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite (active) and space research (active) services

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R RS.577-8

Frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite (active) and space research (active) services

(1982-1986-1990-1994-1995-1997-2006-2009-2026)

Scope

In this Recommendation frequency bands and bandwidths for six basic types of spaceborne active sensors are given. Although the discussion in the Annex mainly concentrates on Earth observation, it is generally believed that the measurement techniques are equally valid on other planets. Therefore, this Recommendation covers both Earth exploration-satellite (active) and space research (active) services.

Keywords

Altimeter, cloud profile radar, earth exploration-satellite service (EESS (active)), radar sounder, remote sensing, scatterometer, synthetic aperture radar (SAR) imager, precipitation radar

Abbreviations/Glossary

EESS	Earth exploration-satellite service
GPM	Global precipitation mission
GPR	Ground-penetrating radar
SAR	Synthetic aperture radar
SWE	Snow water equivalent

The ITU Radiocommunication Assembly,

considering

a) that spaceborne active microwave sensors can provide unique information on physical properties of the Earth and other planets;

b) that the sensing of different physical properties requires the use of different frequencies;

c) that the spatial resolution of the measurement determines the required bandwidth;

d) that simultaneous measurements at a number of frequencies are often needed to distinguish between the various properties;

e) that sharing is generally feasible between spaceborne active microwave sensors operating in the Earth exploration-satellite (EESS) (active) and space research (active) services and terrestrial radars operating in the radiolocation service,

recommends

1 that frequency bands and required bandwidths for spaceborne active sensing may be in accordance with the Annex;

2 that the frequency bands and bandwidths given in Table 1 may be used for active sensing measurements of the Earth for:

– soil moisture;

– vegetation mapping;
– snow distribution, depth and water content;
– geological mapping;
– land use mapping;
– ice boundaries, depth, type and age;
– ocean wave structure;
– ocean wind speed and direction;
– mapping of ocean circulation (currents and eddies);
– oil spills;
– geodetic mapping;
– rain rates;
– cloud height and extent;
– surface pressure;
– measurement of biomass in tropical forests;
– mapping of aquifers and ice sheets;
– etc.

TABLE 1

Frequency band as allocated in Article 5 of the Radio Regulations	**Application bandwidths**					
	Radar sounder	**SAR imager**	**Scatterometer**	**Altimeter**	**Precipitation radar**	**Cloud profile radar**
40-50 MHz	10 MHz					
432-438 MHz		6 MHz				
1 215-1 300 MHz		5-85 MHz	1-4 MHz			
3 100-3 300 MHz		10-200 MHz		200 MHz		
5 250-5 570 MHz		2-300 MHz	0.5-2 MHz	100-320 MHz		
8 550-8 650 MHz		10-20 MHz	5-500 kHz	100 MHz		
9 200-10 400 MHz(1)		5-1 200 MHz	5-500 kHz	300 MHz		
13.25-13.75 GHz		8 MHz	0.4-6 MHz	20-500 MHz	0.6-8 MHz	
17.2-17.3 GHz		8-10 MHz	5-500 kHz		0.6-8 MHz	
24.05-24.25 GHz			5-500 kHz		0.6-8 MHz	
35.5-36 GHz		40 MHz	5-500 kHz	210-500 MHz	0.6-8 MHz	
78-79 GHz					0.6-8 MHz	0.3-10 MHz
94-94.1 GHz						0.3-10 MHz
133.5-134 GHz						0.3-10 MHz
237.9-238 GHz						0.3-10 MHz

(1) See RR No. **5.474A**.

Annex

Factors related to determination of frequency bands and required bandwidths used for spaceborne active sensing

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1 Introduction

Active sensors differ from passive sensors in that they illuminate the object under observation and respond to the reflected energy.

There are six basic types of active sensors:

– radar sounders;
– imagers (synthetic aperture radars (SAR));
– scatterometers;
– altimeters;
– precipitation radars;
– cloud profile radars.

Radar sounders are ground-penetrating radar (GPR) systems which employ lower centre frequencies in order to penetrate the surface of the Earth. This can be used to provide radar maps of subsurface scattering layers to locate and characterize underground water and ice deposits. Specifically, the frequency range of 40-50 MHz represents a trade-off between penetration depth and resolution, and can be used to provide detailed mapping of the spatial distribution of shallow aquifers (on the order to 10-100 m in depth) in arid regions, as well as to perform basal interface topography and determine ice-sheet thickness (on the order of 5 km).

Radar imaging systems are employed to produce high resolution images required by users in such fields as geology, oceanography, agriculture and environmental monitoring. To achieve reasonable spatial resolution from space, synthetic aperture focused radars will be employed for many applications as they have resolutions independent of range. In the area of meteorology scanning Doppler radars may also be employed. Regarding snow water equivalent (SWE) retrieval radar imaging systems, knowledge of SWE is required to understand and predict global climate change and for hydrological applications (water resource management). Multi-frequency microwave sensors operating in the 13 and 17 GHz bands are well suited to monitoring SWE, and can provide global coverage of snow-covered areas at weekly intervals.

Radar scatterometers are useful for determining the roughness of large objects. When operating at frequencies higher than 300 MHz, the scatterometer measures the amount of backscatter from the surface roughness in broad categories ranging from smooth to very rough. At frequencies around 200 MHz, reflectivity depends upon the dielectric constant of the object; at lower frequencies, reflectivity depends primarily upon electrical conductivity. These lower frequencies can be used to penetrate the surface of the Earth to detect sub-surface structures and fall under the purview of radar sounders.

Radar altimetry has yielded three possible operation concepts for practical systems. One of these techniques is based upon the use of a very narrow beamwidth (2 mrad) and a very short transmitted pulse (2 ns). Timing of the round-trip delay of the transmitted pulse leading edge is used to provide altitude information. A technique that is similar to the short pulse system is the pulse compression technique. A short impulse pulse generates a longer frequency modulated pulse and the return, which has a wide bandwidth, is compressed back to a short pulse which is then leading edge detected. The third technique requires moderate antenna size and spacecraft stabilization, with radar return from the nadir point obtained by a time-gating technique. In this system, altitude information is extracted by measuring the centroid of the early portion of the radar waveform rather than the leading edge of a very short pulse.

Knowledge of the global rainfall and cloud distributions is required to understand and predict global climate change. Microwave sensors have a clear advantage over visible/infrared sensors in that they have the capability to penetrate the cloud cover, thereby providing direct information of rain and cloud volume. Active sensors are especially important because they are the only instruments which provide vertical rain and cloud structures, and therefore are essential to study large-scale atmospheric circulation and the radiation budget. Moreover, the active sensors can provide quantitative rain and cloud information independent of the microwave emission properties of background surfaces.

Active remote sensing in the microwave region offers several advantages over visible region sensing and passive microwave sensing, in that it has the capacity to penetrate physical media such as cloud cover and vegetation. Besides being uniquely sensitive to several land/ocean/atmosphere variables (e.g. plant moisture and cloud height), active sensing can, for instance, penetrate the surface and vegetation, operate on an all-weather, day/night basis, attain high spatial resolution SAR enhance features by changing the illumination angle, and operate over broad spectral ranges independently of emissions from narrow-band phenomena.

Active sensors illuminate the object under observation and respond to reflected energy. In order to gather information concerning the Earth’s surface from space, the transmitted signal must traverse the atmosphere twice. As a result, the electromagnetic absorption and scattering properties of the atmosphere play an important role in determining the spectral regions suitable for active remote sensors.

Severe atmospheric attenuation is confined to the shorter wavelengths, and for this reason, active sensors usually operate below the 60 GHz oxygen absorption region and also avoid the spectral region near the 22 GHz water vapour line.

Electromagnetic scattering by precipitation and clouds can present a more serious problem than atmospheric absorption. Echoes from water droplets increase with droplet diameter and decrease with increasing wavelength. Thus, at longer wavelengths clouds give little echo, but precipitation can give somewhat stronger echoes because of the larger particle diameters of the rain drops.

Several aspects of active sensor research, particularly as it relates to the choice of frequencies for measuring Earth-oriented variables from a space platform, are presented below. In determining optimal frequencies, it should be noted that, due to the broad frequency response range of various phenomena of interest, there is often a need for simultaneous measurements at several frequencies so that contributions of the radar return from different sources can be separated.

The radar return from any surface is a function of radar frequency, surface roughness, surface dielectric properties, angle of incidence and aspect, and sub-surface microstructure. In each of the applications listed, the energy reflected back to a radar sensor is strongly affected by at least one backscattering mechanism related to the measured phenomenon. In general, these are: oceanic roughness (used in the study of ocean structure and winds over sea surfaces); O_2 absorption (used in determining surface pressure over oceans); and surface roughness and dielectric constant variations (used in studies of ice, snow and land parameters).

2 Active sensing of ocean surfaces

Oceanic active sensor studies are dominated by wave structure determination, sea-surface wind measurements and ocean current investigations. Generally, the reflected microwave energy is due to ocean roughness: specifically, the radar return is a function of diffraction effects from both large gravity waves and small capillary, surface-tension ripples riding on large-scale waves, and foam. The amount of reflected radiation due to each of these effects observed by an active sensor depends on the sea state and the particular active measurement technique.

Work at several frequencies within the 3-30 GHz range has shown that the effects of large gravity waves dominate at near-normal incidence and those of capillary waves at incidence angles greater than 20 degrees. Thus, to sense sea roughness (a function of the very breeze-dependent ripples) and the size and direction of long-lived gravity waves (coarse sea structure), a two-way component concept is used. In the study of ocean surface winds (important in weather prediction models), the underlying principle is that ocean roughness is a gauge by which wind variables can be inferred, since the small roughness elements which convey the transfer of momentum from the wind to the sea are in at least near equilibrium with the wind.

Using variable frequencies, polarizations and incidence angles, investigators can infer details of ocean surface wind, significant wave height and mean square wave slopes, an accomplishment beyond the capabilities of passive sensing. Experiments have shown that good wind speed sensitivity is obtained at frequencies near 14 GHz and that there is a reduced sensitivity to wind speed at 1.3 GHz.

SARs have shown promise in coarse ocean structure measurements (average significant wave height). One design employs four frequency bands in the 1-17 GHz range and three polarizations with wide-swath and multiple-incidence angle capabilities. Ocean oil slicks suppress short-wavelength ocean waves and therefore the slick area can be discriminated from the surrounding clean surface by microwave imaging radars.

Altimeters have been used successfully from a number of satellites over the world's oceans. For oceanographic studies, an altimeter system having an overall range measurement precision better than 2 cm is required. To achieve 2 cm precision will require removal of the range errors due to ionospheric electron content which cause errors as great as 22 cm at 13.5 GHz. A two-frequency altimeter system can eliminate the range uncertainty due to the ionosphere. A two-frequency altimeter system can also provide accurate measurements of continuous swaths of the ionospheric electron content, measurements which are not available today over large regions of the Earth's oceans. A region of the spectrum, separated by more than an octave from the 13.25-13.75 GHz band, would be a suitable choice for the second frequency. The second frequency could be selected around 5 GHz, with the main frequency remaining near 14 GHz. It is thought that in the longer term, higher frequencies around 35 GHz will also be used.

It can thus be seen that several frequencies have proven useful for the remote active sensing of ocean-wave structure. Due to high wind speed dynamic range and the relative absence of atmospheric effects, wind speed measurement technology has converged on the 10-15 GHz region.

3 Active sensing of the cryosphere

Investigations indicate that the following types of ice variables are amenable in varying degrees to active microwave sensing: ice-type (young, old, etc.), surface roughness, concentration, floe size and number, water openings, drift, surface topology, pressure characteristics, thickness and changes in nature and in distribution of types. Based on these studies, a frequency between 3-30 GHz appears to be the best for determining sea-ice types. A radar frequency in the range 0.3-3 GHz is useful in resolving ambiguities resulting from measurements of thin ice, especially when utilized in conjunction with radars between 3-30 GHz. Higher frequencies are also under consideration.

The most important spaceborne active microwave sensors for sea-ice application are the SAR, radar altimeter and radar scatterometer. Satellite research on sea-ice has been primarily carried out by SAR at 1.3 GHz. Airborne synthetic aperture radar imagery (1.3 and 9.6 GHz) has shown that in some cases, including sea-ice mapping, the higher frequency channel is preferable. Although the interpretability of sea-ice imagery does improve with higher frequencies, there is no question of the usefulness of the product at 1.3 GHz. Altimeters have been used to map sea-ice parameters and the height of the Greenland ice-cap.

Currently, remote sensing of the Earth from space is generally limited to a thin superficial layer, while many issues related to climate, Earth resources or risk monitoring require information over greater depths. Radars operating at frequencies near 435 MHz offer, under certain circumstances, the possibility of imaging through ice layers down to the bed(rock), which could be over 4 km depth. To model global ice sheet dynamics and mass balance (accumulation of snow and losses through melt and iceberg calving) over longer periods (100 to a few 100 000 years), it is essential to have a complete coverage of the Antarctic ice sheet with observations of homogeneous quality, which can be best accomplished using a spaceborne platform employing such as a nadir ice sounder. Radar sounders in the frequency band 40-50 MHz produce sub-surface data products useful in this regard.

SAR imagers operating in 13 and 17 GHz frequency bands are ideally suited for the estimation of SWE (the amount of liquid water stored in solid form by snow) because of the volume scattering properties of dry snow within this frequency range, and the ability to discriminate wet from dry snow cover. SWE and wet/dry snow state are the two parameters which characterize the key aspects of snow required for hydrological and climatological applications. The use of multiple frequency bands in the 13 to 17 GHz range, the frequency dependent influence of snow microstructure (snow gain size and layering properties) can be exploited to retrieve SWE.

4 Active sensing of land surfaces

Interest in active sensing of soil moisture arose due to the limited spatial resolution of passive sensors. The amount of reflected radar power from the soil depends on soil roughness and dielectric constant, vegetation cover and incidence of the transmitted microwave beam. Early laboratory studies showed that soil moisture affects reflectivity of the soil due to changes in soil dielectric constant. Incidence angles less than 45° can help distinguish roughness returns from moisture returns. Research, which utilized 4.7, 5.9 and 13.3 GHz, indicates that a satellite scatterometer system operated at 4.7 GHz with 5° to 17° incidence angles could adequately distinguish soil moisture returns from those of vegetation cover and roughness. However, additional frequencies are needed when vegetation cover is a factor or when sub-soil measurements are required.

On the other hand, vegetation cover has been studied as an objective, particularly in crop identification experiments, where soil returns become an obscuring factor. Both imagers and scatterometers have been used with the reflected power from vegetation being related to vegetation roughness, moisture and dielectric constant, and viewing angle. Results of these investigations indicate that satellites can be useful in active sensor identification of crops and forests, of land use patterns (range, forest, etc.) and of watershed parameters. Multi-spectral, multi-polarization, multi-temporal schemes of observation at high incidence angles (to minimize soil returns) have yielded promising results in research at 1.3, 5.9, 9.0, 9.4, 13, 16, and 35 GHz. Crop classification can be improved by taking growing periods into account, by employing several frequencies and by repeating measurements over several weeks.

Because of the increased penetration into dense vegetation near 400 MHz and increased scattering information, near 400 MHz airborne radars have been used in tropical areas, where vegetation tends to be densest, to aid measuring woody biomass in the tropical forests. These radars have been applied to not only analysing deforestation and reforestation, but also to measure above-ground woody biomass. In several sites of boreal and temperate forests, near 400 MHz horizontal-horizontal, horizontal-vertical and vertical-vertical polarization data produced estimates of total above-ground dry woody biomass within 12% to 27% of the actual biomass, depending on forest complexity. In tropical forests, near 400 MHz radar can assist in estimating their forest biomass and provide results unachievable by any other means, even though biomass levels largely exceed 20 kg/m^2.

Surface penetration near 400 MHz is deeper than for 1 250 MHz by a factor of 8 to 10, and is thus most favourable for Earth penetration studies. It may be possible, using near 400 MHz imaging radars, to document geologic history and climate change within the world's larger deserts using maps of buried fluvial systems and their surrounding topography and to model regional-scale tectonics in semi-arid regions of the world using maps of surface and buried geologic structures, such as faults, fractures, synclines, and anticlines.

5 Active sensing of aquifers and ice sheets

With the advent of GPR active sensing technology has come the desire to use such methods to explore subsurface underground features of the Earth. From characterizing the depth and spatial distribution of shallow aquifers in arid, desertic environments, on the one hand, to charting out the topography and thickness of ice sheets, on the other, use of GPR techniques can be employed to provide a better understanding of climate change and its evolution. Radar sounders are active sensors employing GPR technology which are specifically tailored to such applications.

In order to achieve ground penetration, radar sounders require the use of lower centre frequencies when compared with other active sensors. However, use of lower centre frequencies comes at the cost of larger antenna apertures required in order to maintain focused directivity, along with less available bandwidth for range resolution. A centre frequency value of 45 MHz, coupled with a bandwidth of 10 MHz, was found to represent a suitable trade-off between penetration depth and resolution. In particular, operating over 40-50 MHz allows for the measurement of reflectivity from subsurface scattering layers as deep as 10 m to 100 m for shallow aquifers and groundwater conduits (depending upon the volumetric soil moisture), and on the order of 5 km for basal interface topography and ice-sheet thickness, all while providing a vertical resolution of 5 to 7 m.

The desertic environments in northern Africa and the Arabian Peninsula, along with ice rich regions in Greenland and Antarctica, were initially targeted as areas over which to use spaceborne radar sounders to characterize Earth fossil aquifers and ice sheets, respectively. Coverage of such areas using a spaceborne radar sounder aimed at Earth nadir over an observation epoch on the order of 18 months has been considered as a way to enhancing understanding of the evolution of climate change.

6 Active sensing of the atmosphere

Active sensors can be used to monitor atmospheric precipitation. Thanks to their range-resolved profiling measurements, spaceborne precipitation radars provide unique information on the Earth's hydrological cycle, the vertical distribution of clouds and precipitation and the 3-D structure of storms. Active radars are generally operated in window regions (i.e. regions of the spectrum with low atmospheric attenuation). Since, in the Rayleigh scattering regime, the hydrometeor backscattering cross section depends on $1/\lambda^4$ (where λ is the wavelength), the choice of frequency is generally determined by the target being observed, with shorter wavelengths being used to detect smaller particles. Thus, cm-wavelength radars are referred to as "precipitation radars", while mm-wavelength radars are called "cloud radars".

The radar measured signal, called the reflectivity factor, is proportional to the backscattered radiation and is affected by the attenuation of the radiation along the path between the radar and the target caused by gases and hydrometeors, which tend to increase at higher frequencies. After being corrected for attenuation, the reflectivity signal is generally proportional to the precipitation rate and the condensed water content, though this relation is strongly dependent on the hydrometeor size distribution with large particles contributing the most to the signal. This dependency generally causes large uncertainties when retrieving microphysical quantities (like rain rate, water equivalent content, characteristic size). Techniques based on multifrequency and Doppler radar observations as adopted in the GPM (Global Precipitation Mission) and for the EarthCARE mission have the potential to reduce such uncertainties. Because they provide vertical profiles, radars represent a unique and irreplaceable component of the global observing system and are often used as reference products. For instance, the use of passive bands has benefited from coincident measurements from spaceborne cloud and precipitation radars (e.g. CloudSat's Cloud Profile Radar in W-band and GPM's Dual Precipitation Radar in Ku- and Ka-band).

The current atmospheric spaceborne radars use only frequencies in the 13.25-13.75 GHz, 35.5-36 GHz and 94.0-94.1 GHz bands, but new technology developments are paving the way toward:

– the exploitation of lower bands (e.g. the 9.2-10.4 GHz band) thanks to deployable antennas that will enable, even at low frequencies, spatial resolution compatible with cloud and precipitation structure, i.e. $\leq$ 5 km;
– the use of higher frequency bands (above 110 GHz) thanks to more powerful transmitters that will attain radar sensitivities comparable or better than those achieved at the lower frequencies.

A smaller radar wavelength (3 mm is the smallest currently measured from space) will allow better characterization of mm and sub-mm sized particles because of an enhancement in the levels of attenuation and of non-Rayleigh effects. In particular, the inclusion of frequencies in the G-band (typically in synergy with radars in the Ka- or W-band) can significantly improve current micro- and macro-physical profiling capabilities in three key areas: boundary layer clouds, cirrus and mid-level ice clouds and precipitating snow.

In addition, technology developments are currently being made that could enable water vapor sounding at high resolution using higher frequency bands, near 325 GHz and 380 GHz.

It is also interesting to note that recent studies have sparked interest in the use of differential absorption radar systems, with multiple frequencies allocated not in window regions but within absorption bands of oxygen or water vapor. The differential signal between different channels can be used to retrieve profiles of the absorbing gas. This can also provide surface pressure measurements over the ocean.

7 Meteorological and climatological observations

The knowledge gained in ground-based and airborne measurement of rainfall, storm features and pressure fields in weather prediction models has also been extended to spaceborne systems. The techniques are based upon changes in clear atmosphere refractive index due to rain-related features or differential reflectivities of multi-frequency echoes. Studies carried out with orthogonally polarized radars and multiple, narrow-beam coverage at several frequencies between 2 and 37.5 GHz have been able to measure precipitation rate, intensity, spatial distribution, drop size and surface pressure over oceans and wind movements within storms. There are several factors constraining frequency choices. A combination of bands must be chosen to match minimum sensitivity and spatial resolution, yet not be swamped by ground echo at needed viewing angles. Only downward-looking scanning pencil beams (as opposed to azimuthal or cross-track fan beams) have the capacity to infer rainfall intensity from altimeter estimates of the freezing layer. Single and multi-frequency approaches to the measurement of rain attenuation as well as radar reflectivities have the capability for quantitative retrieval of vertical precipitation profiles from satellites.

A frequency near 94 GHz is preferred and used for spaceborne cloud profile radars based upon the following factors: minimum detectable cloud reflectivity, propagation and scattering, resolution, antenna beam interference, previous work and technology. The reflectivity of marine stratus clouds, which are very important to the determination of the Earth's radiation budget, may be as low as −30 dBZ (decibel units of reflectivity) a level 70 dB below the reflectivity of rain (10 mm/h). The objective of a spaceborne cloud profiling mission is to measure the reflectivity profile for all clouds within the field of view having a reflectivity as low as −30 dBZ. A frequency near 94 GHz is needed to measure this reflectivity level while also meeting along track resolution objectives. A large amount of experimental work in the form of ground-based and airborne radar systems development and data collection has been done near 94 GHz. Along with this hardware development has been computational work aimed at studying the behaviour of non-Rayleigh scatterers near 94 GHz.

8 Bandwidth requirements for active sensing

Bandwidth requirements for active sensors vary with the type of sensor, i.e. radar sounder, SAR imager, scatterometer, altimeter, precipitation radar, or cloud profile radar. In all cases, the bandwidth is determined by the required range resolution and is equal to:

$$B = \frac{1}{\tau} = \frac{c}{2\Delta R} \tag{1}$$

where:

- B: bandwidth (Hz)
- τ: pulse duration (equivalent to the inverse of the pulse compression bandwidth) (s)
- c: speed of light (m/s)
- ΔR: range resolution along the radar beam (m).

It is noted that the range resolution on the surface (or cross-track resolution) of side-looking radars, denoted here by ΔR_s, is given for the case of a spherical Earth model by:

$$\Delta R_s = \Delta R/\cos\gamma = \Delta R/\left((1 + h/R_E)\cos\theta_d\right) \qquad (2)$$

where:

- γ : grazing angle or arrival angle on the surface of the Earth
- θ_d : depression angle from the satellite
- h : altitude of the satellite
- R_E : radius of the Earth (approximately 6 378 km).

For typical EESS satellite altitudes, which are less than 800 km, the approximation $h/R_E \approx 0$ is often used, resulting in the approximation $\Delta R_s \approx \Delta R/\cos\theta_d$. For instance, a bandwidth of 100 MHz gives a value of 1.5 m for ΔR, the range resolution along the radar beam, and at a depression angle of 60 degrees, this range resolution on the surface $\Delta R/\cos\theta_d$ is 3 m. For a bandwidth of 500 MHz for finer resolution, this gives a value of 0.3 m for ΔR, and at a depression angle of 60 degrees, this range resolution on the surface is 0.6 m. In the case of rain and cloud radars where a large number of independent samples should be obtained in a short dwell time at each scan position, the frequency agility technique may be employed. In this case, the total bandwidth of the radar will require $B \times N_f$ or more (N_f is the number of frequency channels in the frequency agility system), considering the frequency separation to keep necessary isolation between the radar receiver channels.

In conclusion, a bandwidth of 100 MHz would be compatible with a large majority of applications envisaged by scientists for spaceborne active microwave sensors except altimeters and fine resolution SAR, for which larger bandwidths are required.

9 Summary of frequency bands and necessary bandwidths for active sensing

Although active microwave sensing technology is advancing rapidly and much still needs to be learned, a set of frequency bands can be defined which satisfy measurement requirements and provide for multi-frequency measurements needed to separate signal contributions from different sources. Sharing considerations dictate that specific frequency bands for active sensors should be in bands shared with the radiolocation service. Thus, frequency bands for active spaceborne sensor measurements fall near 45 and 435 MHz, as well as near 1, 3, 5, 10, 14, 17, 24, 35, 78, 94, 133 and 238 GHz. Use of higher frequencies (near 325 and 380 GHz) is also under investigation. Typical bandwidths used by EESS (active) sensors in various frequencies can be found in the Recommendation ITU-R RS.2105. Altimeter measurements may need up to 500 MHz bandwidth to satisfy accuracy requirements, but, at present, this requirement can be accommodated only in the bands allocated near 14 and 35 GHz for active sensing. A second frequency band, with 500 MHz bandwidth would achieve 2 cm precision for the application of altimeters to oceanography. Another frequency band which would be useful for achieving this precision is, for instance, around 5 GHz. For a SAR bandwidth of 500 MHz for finer resolution, at a depression angle of 60 degrees, this range resolution on the surface is submeter at 0.6 m. A minimum bandwidth of 6 MHz near 435 MHz is sufficient for applications using SAR for measurements of soil moisture and biomass and for documentation of geologic history and climate change by measuring the extent and thickness of the global ice sheets and the subsurface mapping of arid and semi-arid regions. Multi frequency measurements in the 13 and 17 GHz bands are ideally suited for snow mass retrievals, a required variable for hydrological and climatological applications.