RECOMMENDATION ITU-R SA.515-3

FREQUENCY BANDS AND BANDWIDTHS USED FOR SATELLITE PASSIVE SENSING

(Question ITU-R 140/7)

(1978-1990-1994-1997)

The ITU Radiocommunication Assembly,

considering

a) that environmental data relating to the Earth is of increasing importance;

b) that passive microwave sensor technology is used in remote sensing by Earth exploration and meteorological satellites in certain frequency bands allocated for such use in the Radio Regulations;

c) that some of these bands are also allocated to other radio services;

d) that protection from interference on certain frequencies is essential for passive sensing measurements and applications;

e) that for measurements of known spectral lines, certain bands at specific frequencies are of particular importance;

f) that, for other types of passive sensor measurements, a certain number of frequency bands are in use, the exact positions of which in the spectrum are not of critical importance as long as the centre frequencies are more or less uniformly distributed in the spectrum;

g) that the preferred and essential frequencies and bandwidths need to be promulgated;

h) that new frequencies may be identified in the future which would enable new types of measurements,

recommends

1 that, based on Annexes 1 and 2, the frequency bands and the associated bandwidths necessary for passive sensing of properties of the Earth's land, oceans and atmosphere are as shown in Table 1;

2 that the use of frequencies from Table 1 be encouraged for passive sensors.

TABLE 1

Frequency (GHz)	Necessary bandwidth (MHz)	Measurements
Near 1.4	100	Soil moisture, salinity, sea temperature, vegetation index
Near 2.7	60	Salinity, soil moisture
Near 4	200	Ocean surface temperature
Near 6	400	Ocean surface temperature
Near 11	100	Rain, snow, ice, sea state, ocean wind
Near 15	200	Water vapour, rain
Near 18	200	Rain, sea state, ocean ice, water vapour
Near 21	200	Water vapour, liquid water
22.235	300	Water vapour, liquid water
Near 24	400	Water vapour, liquid water
Near 31	500	Ocean ice, water vapour, oil spills, clouds, liquid water

TABLE 1 *(continued)*

Frequency (GHz)	Necessary bandwidth (MHz)	Measurements
Near 37	1 000	Rain, snow, ocean ice, water vapour
50.2-50.4	200	Temperature profiling
52.6-59.0	6 400(1)	Temperature profiling
60.3-61.3	1 000(1)	Temperature profiling (upper atmosphere)
Near 90	6 000	Clouds, oil spills, ice, snow
100.49	2 000	Nitrous oxide
110.80	2 000	Ozone
115-122	7 000(1)	Temperature, carbon monoxide
125.61	2 000	Nitrous oxide
150.74	2 000	Nitrous oxide
155.5-158.5	3 000	Earth and cloud parameters
164-168	4 000	Nitrous oxide, cloud water and ice, rain, chlorine oxide
175-192	17 000(1)	Water vapour, nitrous oxide, ozone
200.98	2 000	Nitrous oxide
217-231	14 000	Clouds, humidity, nitrous oxide
230.54	2 000	Carbon monoxide
235.71	2 000	Ozone
237.15	2 000	Ozone
251.21	2 000	Nitrous oxide
276.33	2 000	Nitrous oxide
301.44	2 000	Nitrous oxide
325.10	2 000	Water vapour
345.80	2 000	Carbon monoxide
364.32	2 000	Ozone
380.20	2 000	Water vapour

(1) This bandwidth occupied by multiple channels.

ANNEX 1

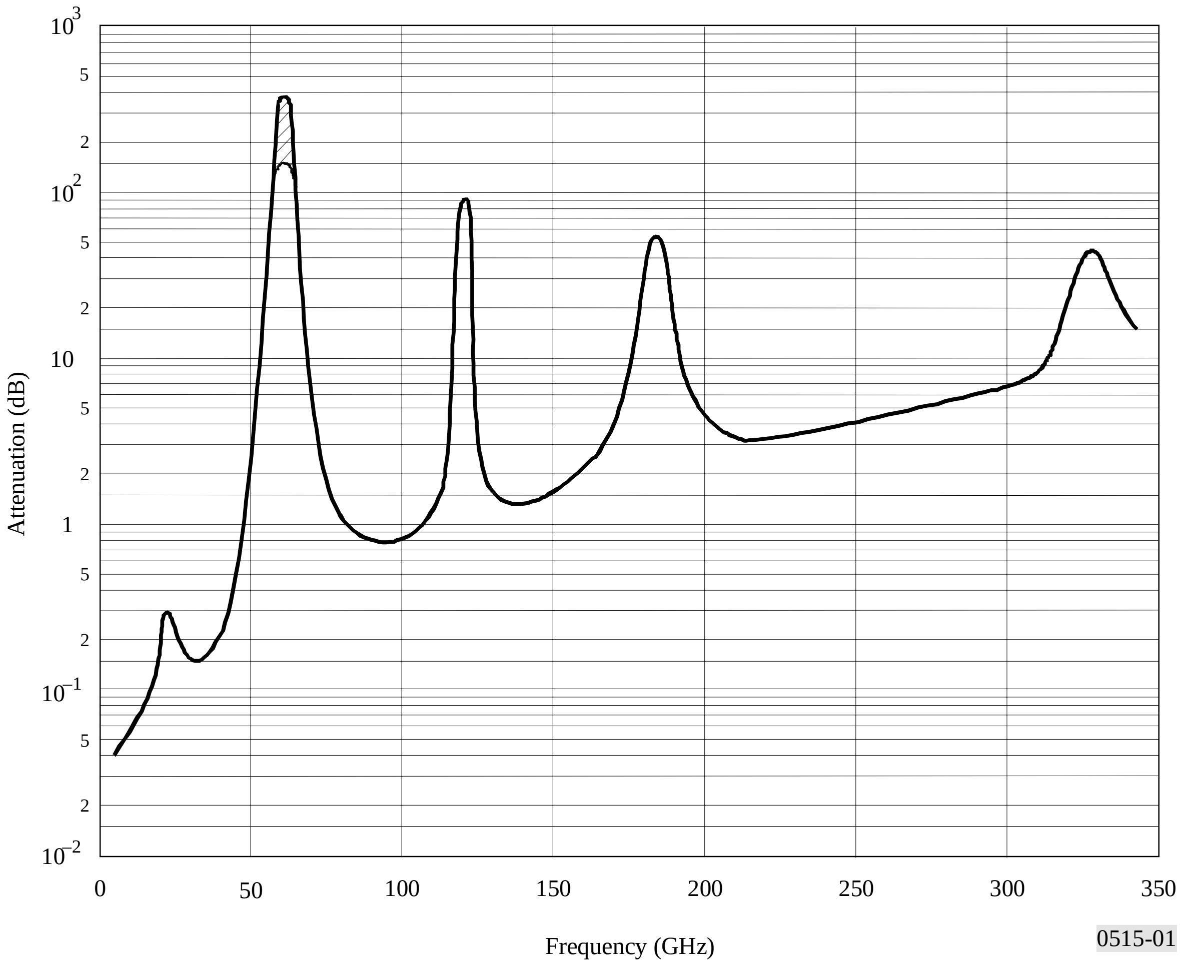
Selection of frequencies for satellite passive sensing

1 Introduction

Energy at microwave frequencies is emitted and absorbed by the surface of the Earth and by the atmosphere above the surface. The transmission properties of the absorbing atmosphere vary as a function of frequency, as shown in Fig. 1. This figure depicts calculated one way zenith (90° elevation angle) attenuation values for oxygen and water vapour. The calculations are for a path between the surface and a satellite. These calculations reveal frequency bands for which the atmosphere is effectively opaque and others for which the atmosphere is nearly transparent. The regions or windows that are nearly transparent may be used to sense surface phenomena; the regions that are opaque are used to sense the top of the atmosphere.

FIGURE 1

Zenith attenuation versus frequency
(January, mid-latitude 7.5 g/m^3 surface water vapour density)



The surface brightness temperature, the atmospheric temperature at points along the path, and the absorption coefficients are unknown and to be determined from measurements of the antenna temperature, T_A. The surface brightness temperature and the absorption coefficients in turn, depend upon the physical properties of the surface or atmosphere that are to be sensed. A single observation at a single frequency cannot be used to estimate a single physical parameter. Observations must be made simultaneously at a number of frequencies and combined with models for the frequency dependence and physical parameter dependence of the surface brightness temperature and of the absorption coefficient, before solutions can be obtained.

Operating frequencies for passive microwave sensors are primarily determined by the phenomena to be measured. For certain applications, such as those requiring measurements of microwave emissions from atmospheric gases, the choice of frequencies is quite restricted and is determined by the spectral line frequencies of the gases. Other applications have broad frequency regions where the phenomena can be sensed.

2 Atmospheric measurements

Atmospheric attenuation does not occur within a single atmospheric layer of constant temperature. The measured antenna temperature depends mostly upon the temperature in the region along the path where the attenuation (total to the satellite) is less than 10 dB, and little upon temperatures in regions where the attenuation is very small, or the total attenuation to the satellite is large. The temperature values can be sensed at different heights or distances along the path by selecting frequencies near the edges of the opaque regions with different attenuations, which provide different weighting functions or multipliers of *T(s)*, the atmospheric temperature at a given point.

A number of different frequencies may be chosen to provide a reasonable set of weighting functions for atmospheric temperature, water vapour, ozone, chlorine oxide, nitrous oxide and carbon monoxide profile measurements. For the last four molecular measurements, each individual line does not have enough fine structure, as in the O_2 temperature profiling band, or enough width, as in the water vapour band about 22.235 GHz, to allow for profile measurements about a line, given the satellite constraints on integration time. Hence, in order to achieve profiling information on these constituents, multiple line measurements will be necessary.

Atmospheric temperature profiles are currently obtained from spaceborne sounding instruments measuring in the infrared (IR) and microwave spectrums (oxygen absorption around 60 GHz).

As compared to IR techniques, the all-weather capability (the ability for a spaceborne sensor to "see" through most clouds) is probably the most important feature that is offered by microwave techniques. This is fundamental for operational weather forecasting and atmospheric sciences applications, since more than 60% of the Earth's surface, in average, is totally covered by clouds, and only 5% of any 20×20 km^2 spot (corresponding to the typical spatial resolution of the IR sounders) are completely cloud-free. This situation severely hampers operation of IR sounders, which have little or no access to large, meteorologically active regions.

The broad opaque region between 50 and 66 GHz is composed of a number of narrow absorption (opaque) lines and observations may be made either at the edges of the complex of lines or in the valleys between the lines. The next O_2 absorption spectrum around 118 GHz has a lower potential due to its particular structure (monochromatic, as compared to the rich multi-line structure around 60 GHz) and is more heavily affected by the attenuation caused by atmospheric humidity.

Clouds and rain can provide additional attenuation when they occur along the path. Both rain and clouds may be sensed in the atmospheric windows between 5 and 150 GHz. Multiple observations over a wide frequency range are required to separate rain from cloud and to separate these effects from surface emission.

3 Land and ocean measurements

Emission from the surface of the Earth is transmitted through the atmosphere to the satellite. When the attenuation values are high, this emission cannot be sensed. When it is low, as required to sense the temperature of the lowest layer of the atmosphere, both the surface and atmospheric contributions are combined. Additional measurements within the window channels are required to separate the two types of contributions. Surface emission is proportional to the temperature and emissivity of the surface. The latter is related to the dielectric properties of the surface and to the roughness of the surface. If the emissivity is less than unity, the surface both emits and scatters radiation. The scattered radiation originates from downward atmospheric emission from above the surface. In a window channel with very small attenuation values this latter contribution is negligible: otherwise it must be considered in the solution.

Surface brightness temperatures do not show the rapid variation with frequency exhibited by emission from atmospheric absorption lines. The relatively slow frequency variations of the effects due to surface parameters requires simultaneous observations over a broad frequency range within the atmospheric windows to determine their values. Separation of the parameters can only be accomplished when the parameters have different frequency dependences. The brightness temperature of the ocean surface is a function of salinity, temperature and wind. The wind affects the brightness temperature by roughening the surface and by producing foam which has dielectric properties different from the underlying water. Salinity is best sensed at frequencies below 3 GHz and, if extreme measurement accuracy is required, at frequencies below 1.5 GHz. Sea surface temperature is best sensed using frequencies in the 3 to 10 GHz range, with 5 GHz being near optimum. Wind affects observations at all frequencies but is best sensed at frequencies above 15 GHz.

Surface layers of ice or oil floating on the ocean surface have dielectric properties different from water and can be sensed due to the resultant change in brightness temperature. Oil slicks can change the brightness temperature above 30 GHz by more than 50 K and ice can change the brightness temperature by more than 50 K at frequencies from 1 to 40 GHz. Although ice and oil spills can provide a large change in brightness temperature, a number of observations in each of the atmospheric windows are required to separate the effects of ice and oil from rain and clouds.

The moisture content of the surface layers can be detected at microwave frequencies. The brightness temperature of snow and of soil both change with moisture content and with frequency. In general, the lower the frequency, the thicker the layer that can be sensed. Since the moisture at the surface is related to the profile of moisture below the surface, observations at higher frequencies can also be useful. In sensing the melting of snow near the surface, observations at 37 GHz and higher provide the most information. For sensing soil, especially soil under a vegetation canopy, frequencies below 3 GHz are of most interest. In practice, a number of frequencies are required, first to classify the surface as to roughness, vegetation cover, sea ice age, etc., and, second, to measure parameters such as ice thickness or moisture content.

ANNEX 2

Factors related to determination of required bandwidths

1 Sensitivity of radiometric receivers

Radiometric receivers sense the noise-like thermal emission collected by the antenna and the thermal noise of the receiver. By integrating the received signal the random noise fluctuations can be reduced and accurate estimates can be made of the sum of the receiver noise and external thermal emission noise power. Expressing the noise power per unit bandwidth as an equivalent noise temperature, the effect of integration in reducing measurement uncertainty can be expressed as given below:

$$\Delta T_e = \frac{\alpha \left(T_A + T_N \right)}{\sqrt{B\tau}}$$

where:

ΔT_e: r.m.s. uncertainty in the estimation of the total system noise, $T_A + T_N$

α: receiver system constant

T_A: antenna temperature

T_N: receiver noise temperature

B: bandwidth

τ: integration time.

At wavelengths longer than 3 cm, a receiver noise temperature of less than 150 K can be obtained with solid-state parametric amplifiers. At wavelengths shorter than 3 cm, the most common type of receiver currently used today is the superheterodyne with a noise temperature ranging from several hundred degrees at 3 cm wavelength to perhaps 2 000 K at 3 mm wavelength. Improvements in high electronic mobility transistors technology is going to render possible the utilization of low-noise preamplifiers, with a receiver noise temperature of about 300 K at 5 mm wavelength.

Beyond the improved receiver noise temperature that can be obtained with the introduction of low-noise preamplifiers, significant reductions in the ΔT_e values (or increased sensitivity) can only be accomplished in spaceborne radiometers by increased system bandwidths and by introducing instrument configurations that enable optimization of the integration time. Depending on the spatial resolution required, low-orbit spaceborne radiometers are limited to integration times of the order of seconds or less, due to the spacecraft relative velocity.

2 Technical parameters of passive sensors

2.1 Case of scanning radiometers

Studies have been performed to determine sensor sensitivity requirements, spatial resolution requirements, and non-scanning bandwidth requirements. The results of the studies are summarised in Table 2 for each of the preferred frequencies. Also presented in Table 2 is the coverage width that can be achieved with the suggested bandwidths by use of scanning sensors. It should be noted that 185 km coverage widths result in total Earth coverage in about 18 days for a typical EES orbit such as that used by the Landsat series of satellites. Updating at a period of less than every 18 days is required to fully satisfy the requirements of environmental scientists and meteorologists.

TABLE 2

Technical considerations for passive spaceborne sensors (using scanning radiometers)

Frequency (GHz)	Primary application	Required ΔT_e (K)	Resolution (km)	System noise temperature (K)	Non-scan bandwidth (MHz)	Suggested bandwidth (MHz)	Coverage width (km)
Near 1.4	Soil moisture, salinity, sea temperature, vegetation index	0.1	20	450	42	100	48
Near 2.7	Salinity, soil moisture	0.1	2	450	60	60	2
Near 4	Ocean surface temperature	0.3	2	450	45	200	9
Near 6	Ocean surface temperature	0.3	20	450	5	400	1 600
Near 11	Rain(1), snow, ice, wind	1.0	1	1 000	60	100	2
Near 15	Water vapour, rain	0.2	2	1 000	180	200	2
Near 18	Rain(1), snow, ice, wind, water vapour	1.0	2	1 000	180	200	2
Near 21	Water vapour, liquid water	0.2	2	1 000	180	200	2
22.235	Water vapour, liquid water	0.4	2	1 000	45	300	13
Near 24	Water vapour, liquid water	0.2	2	1 000	180	400	4
Near 31	Ice, oil spills, clouds	0.2	2	1 000	180	500	6
Near 37	Rain, snow, ice, water vapour	1.0	1	2 300	230	1 000	4
50.2-61.3	Atmosphere temperature profiling	0.3	10	2 300	235	Multiple(2)	10
Near 90	Clouds, oil spills, ice, snow	1.0	1	2 300	230	6 000	26
Above 100	Nitrous oxide, O_3, CO, H_2O, ClO, temperature	0.2	1	4 300	1 850	2 000	1

(1) Parameters given for this application.

(2) Several bands between 50.2 and 61.3 GHz.

2.2 Case of pushbroom radiometers

Improved coverage width and reduced bandwidth can be obtained through the use of pushbroom radiometers. Lower values of ΔT_e can also be obtained because a longer integration time per observation is possible. For the range 50-66 GHz, the technical considerations are given in Table 3.

TABLE 3

Technical considerations for passive spaceborne sensors (using pushbroom radiometers)

Frequency (GHz)	Primary application	Required ΔT_e (K)	Resolution (km)	System noise temperature (K)	Suggested bandwidth (MHz)	Coverage width (km)
50.2-61.3	Atmospheric temperature profiling	0,1	10	550	20[(1)]	2 000

(1) Several bands of 20 MHz.