Galactic Noise and Passive Microwave Remote Sensing From Space at L-Band

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***Abstract*—The spectral window at L-band (1.413 GHz) is important for passive remote sensing of soil moisture and ocean salinity from space, parameters that are needed to understand the hydrological cycle and ocean circulation. At this frequency, radiation from celestial (mostly galactic) sources is strong and, unlike the constant cosmic background, this radiation is spatially variable. This paper presents a modern radiometric map of the celestial sky at L-band and a solution for the problem of determining what portion of the sky is seen by a down-looking radiometer in orbit. The data for the radiometric map are derived from recent radio astronomy surveys and are presented as equivalent brightness temperature suitable for remote sensing applications. Examples using orbits and antennas representative of those contemplated for remote sensing of soil moisture and sea surface salinity from space are presented to illustrate the signal levels to be expected. Near the galactic plane, the contribution can exceed several Kelvin.**

***Index Terms*—Galactic background, microwave radiometry, ocean salinity, remote sensing.**

I. Introduction

THE SPECTRAL WINDOW 1.400–1.427 GHz (L-band) reserved for passive use only is important for measuring parameters of the earth's surface such as soil moisture and ocean salinity that are needed for understanding the hydrological cycle and energy exchange with the atmosphere. Being able to make observation at the long wavelength end of the microwave spectrum is critical to these measurements. In the case of soil moisture, long wavelengths increase penetration into the soil and mitigate effects of attenuation through the vegetation canopy and the effects of surface roughness. In the case of sea surface salinity, long wavelengths improve the sensitivity to salinity and minimize the dependence on surface roughness.

However, at L-band, radiation from extraterrestrial sources is not negligible, and one needs to know the brightness temperature of the celestial sky to correct for down-welling radiation that is reflected from the surface into the receiver [1], [2]. This contribution is of particular concern for remote sensing of sea surface salinity because the surface is a good reflector and the salinity signal itself is relatively small [3]–[5]. The problem is exacerbated by the fact the down-welling radiation is not a constant across the celestial sky, being significantly stronger in the galactic plane [4], [6]. This is a particular concern in the case of remote sensing from space because the portion of the celestial sky that contributes radiation changes rapidly as the sensor moves through its orbit. In addition, the orbit itself may change its orientation with respect to the celestial sky, as is the case with sun-synchronous orbits that precess as the earth rotates around the sun in order to keep the orientation of the orbit constant with respect to the sun.

Previous estimates of the magnitude and distribution of the background radiation for use in remote sensing have been rather coarse [4], [6], [7]. However, recent surveys of the radio sky at 1.4 GHz [8]–[13] have made it possible to produce maps with sufficient spatial and radiometric accuracy to be relevant to remote sensing applications. Using this data, this paper presents a modern map of the radiometric sky at L-band and a solution to the problem of determining the portion of the sky seen by a down-looking radiometer in orbit. The data are presented as equivalent brightness temperature for ease of use in remote sensing applications. Examples using orbits and antennas representative of those used for remote sensing of soil moisture and sea surface salinity are presented to illustrate the signal levels to be expected.

II. Radio Sky at L-Band

There are three important sources of radiation within the L-band window at 1.413 GHz that originate outside of our solar system: the cosmic microwave background (CMB), discrete line emission from (mostly) neutral hydrogen, and continuum emission such as is emitted by thermal sources. The latter two are the subject of this paper, but all three are discussed for completeness.

A. Cosmic Background

The cosmic microwave background radiation is a remnant of the origin of the universe in a "big bang." Although the recent cosmological research has focused on details of its spatial distribution [14], these variations (milli-Kelvin) are not important for applications such as remote sensing of soil moisture or ocean salinity from space. For remote sensing applications, the cosmic background radiation is essentially constant in both space and time with a value of about 2.7 K. This background radiation can contribute to a measurement with a down-looking radiometer in a direct manner if, for example, the radiometer antenna has side lobes above the horizon. It also can contribute via reflection of down-welling radiation off the surface [1], [2]. The latter is especially important in remote sensing of the ocean surface where the reflection coefficient is relatively large. The cosmic background will be included in the examples to be presented here; but, since it is uniform and constant over the spectral window, it is relatively easily included in radiometer retrieval algorithms.

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TABLE I
SUMMARY OF THE SURVEY PARAMETERS. *NOTES: α IS RIGHT ASCENSION. δ IS DECLINATION

Parameters	Stockert Continuum Survey	IAR Continuum Survey	Leiden/Dwingeloo Hydrogen Survey	IAR Hydrogen Survey
Coverage*	$0° \leq \alpha \leq 360°$ $\delta \geq -19°$	$0° \leq \alpha \leq 360°$ $\delta \leq -10°$	$0° \leq \alpha \leq 360°$ $\delta \geq -30°$	$0° \leq \alpha \leq 360°$ $\delta \leq -25°$
HPBW (effective)	~35′	35′.4	36′	30′
Effective sensitivity	50 mK	~50 mK	70 mK	70 mK
Accuracy	Scale: 5 % Zero: 0.5K	Scale: 5 % Zero: 0.5K	0.1 K	5%
Effective bandwidth	18MHz	13 MHz		
Antenna diameter	25 m	30 m	25 m	30 m

B. Line Emission

The window at 1.413 GHz was protected for passive use because of the interest in emission from a hyperfine transition in neutral hydrogen that occurs in this window. The original proposal that such radiation could be detected from neutral hydrogen in our galaxy is attributed to Oort and van de Hulst, and the first observations were made by Ewen and Purcell in 1951 [15]. This radiation provides information on the temperature, density and motion of hydrogen. The radiation is concentrated around the plane of the galaxy, but clouds of hydrogen are widespread and no direction is observed without some radiation.

Recently, Hartman and Burton [12] motivated by the high-quality, all-sky surveys being made at other wavelengths reported a new survey of line emission by hydrogen. This survey, the "Leiden/Dwingeloo" survey in Table I, used a 25-m radio telescope and covered the sky above declination of $-30°$. The survey was recently complemented by data collected with the 30-m antenna at the Instituto Argentino de Radioastronomia (IAR) and reported by Arnal *et al.* [13]. The IAR survey (Table I) covered declinations south of $-25°$ filling in the missing portions of the southern sky. The result of the two surveys is data over the entire celestial sphere with sufficient spatial resolution $(0.5° \times 0.5°)$ and radiometric resolution $(\Delta T < 0.1$ K) to be applicable to remote sensing at L-band from space, including high-resolution sensors proposed for the future (e.g., a spatial resolution of $0.5° \times 0.5°$ corresponds to an aperture of about 25 m).

VII. CONCLUSION

In addition to the uniform cosmic background radiation, there is additional radiation (line emission from hydrogen and a continuum background) that must be taken into account for remote sensing at L-band. In contrast to the CMB, this additional radiation is spatially varying and strongest in the direction of the plane of the galaxy. The effective brightness temperature of down-welling radiation from these sources that is reflected from the surface into the radiometer depends on the antenna beam width and surface conditions. For a perfectly reflecting surface (reflectivity of unity) and an antenna with a beam width on the order of 10°, the peak contribution from sources other than the CMB is on the order of 1–6 K, varying with the orientation of the sensor and orbit. The fact that this signal can change both seasonally and with the location of the sensor in its orbit makes its presence an important issue for remote sensing of the earth. How important these changes in the background radiation are depends on the applications and surface conditions. For example, it is less an issue for applications such as the remote sensing of soil moisture where the signal is large and the reflectivity at the surface small (on the order of 0.3). However, it is more important for remote sensing applications such as the measurement of sea surface salinity where the reflectivity of the surface is large (on the order of 0.7) and the signal is small (on the order of 0.5 K/psu). In the latter case, careful mapping of the down-welling radiation will be an important issue.