Brightness Temperature of a Flat Water Surface

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1 Introduction

A flat water surface will be an important target for use in radiometer tests. This note describes prediction of the brightness temperature T_B of a flat water surface. The parameters involved are:

- the frequency f (Hz), polarization (horizontal h or vertical v), and polar observation angle θ of an observing radiometer
- The physical temperature T of the water surface (Celsius)
- The salinity S of the water in grams of salt/kilogram water. Units are also known as "practical salinity units" or psu.

The pattern of the observing antenna is neglected in the following. The symbol ϵ is used to represent the relative permittivity of the water.

2 Permittivity of water

Two models of the permittivity of sea water [1]-[2] are commonly applied at present. The older model [1] has been found more successful at reproducing water surface observations at L-band [3]. According to this model, the relative permittivity of sea water is given by

$$\epsilon = \epsilon_\infty + \frac{(\epsilon_1 - \epsilon_\infty)}{1 - i f \tau} + \frac{i\sigma}{\omega \epsilon_0} \tag{1}$$

where ϵ_0 is the permittivity of free space, f is the frequency of the radiometer in Hertz, and

$$\begin{aligned}
\epsilon_1 &= (87.134 - 0.1949T - 0.01276T^2 + 0.0002491T^3) \\
&\quad (1 + 1.613 \times 10^{-5} TS - 0.003656S + 3.21 \times 10^{-5} S^2 - 4.232 \times 10^{-7} S^3) && (2) \\
\epsilon_\infty &= 4.9 && (3) \\
2\pi\tau &= (1.1109 \times 10^{-10} - 3.824 \times 10^{-12} T + 6.398 \times 10^{-14} T^2 - 5.096 \times 10^{-16} T^3) \\
&\quad (1. + 2.282 \times 10^{-5} TS - 7.638 \times 10^{-4} S - 7.760 \times 10^{-6} S^2 + 1.105 \times 10^{-8} S^3) && (4) \\
\sigma &= S(.18252 - 0.0014619S + 2.093 \times 10^{-5} S^2 - 1.282 \times 10^{-7} S^3) \\
&\quad \exp((T-25)(0.02033 + 0.0001266(25-T) + 2.464 \times 10^{-6}(25-T)^2 \\
&\quad -S(1.849 \times 10^{-5} - 2.551 \times 10^{-7}(25-T) + 2.551 \times 10^{-8}(25-T)^2))) && (5)
\end{aligned}$$

A nominal value at 1413 MHz, $T = 10$ C, $S = 35$ grams/Kg is $\epsilon = 74.83 + i56.01$.

3 Brightness temperature of a flat interface

For a flat interface, Kirchhoff's law states that the brightness temperature (Kelvin) is given by

$$T_B = (T + 273.16)\left(1 - |\Gamma|^2\right) \tag{6}$$

where Γ is the Fresnel reflection coefficient of the flat interface:

$$\Gamma = \frac{\cos\theta - \sqrt{\epsilon - \sin^2\theta}}{\cos\theta + \sqrt{\epsilon - \sin^2\theta}} \tag{7}$$

for horizontal polarization, or

$$\Gamma = \frac{\epsilon\cos\theta - \sqrt{\epsilon - \sin^2\theta}}{\epsilon\cos\theta + \sqrt{\epsilon - \sin^2\theta}} \tag{8}$$

for vertical polarization. The value of ϵ found in the previous section and knowledge of T and θ are thus sufficient to predict the water surface brightness temperature.

4 Example values

Figure 1 plots variations in horizontal and vertical brightness temperatures with observation angle for frequency 1413 MHz, surface temperature 5 C, and salinity 35 psu. The plot demonstrates the standard flat surface behaviors, with a strong Brewster angle effect in vertical polarization. Note observation angles in the 45° to 55° range are preferred for Earth observing satellites due to swath considerations. A strong contrast between polarizations is observed for sea water in this range of angles.

Figure 2 plots variations in horizontal and vertical brightness temperatures with surface temperature T for frequency 1413 MHz, salinity 35 psu, and observation angle 50 degrees. The dependence of ϵ on temperature results in a more complex variation than the simple $T + 273.16$ factor multiplying the brightness temperature in equation (6).

Figure 3 plots variations in horizontal and vertical brightness temperatures with frequency from 1300 to 1500 MHz, for surface temperature $T = 20$ C, observation angle 50 degrees, and salinity 35 psu. A relatively strong variation in frequency is observed; we will need to account for this with our widebandwidth system. In the 100 MHz bandwidth centered on 1413 MHz, the horizontal brightness is predicted to increase from 63.2 K to 64.4 K while the vertical brightness is predicted to increase from 130.3 K to 132.3 K.

5 Sensitivity to salinity

Since the eventual goal of our project is to apply the technology to sea salinity sensing systems, it is worthwhile to examine the sensitivities that result from the model. In the open ocean, salinity values are expected to vary in the range 32 to 37 psu. NASA desires remote measurements of salinity that are accurate to within 0.2 to 0.3 psu. Figure 4 plots

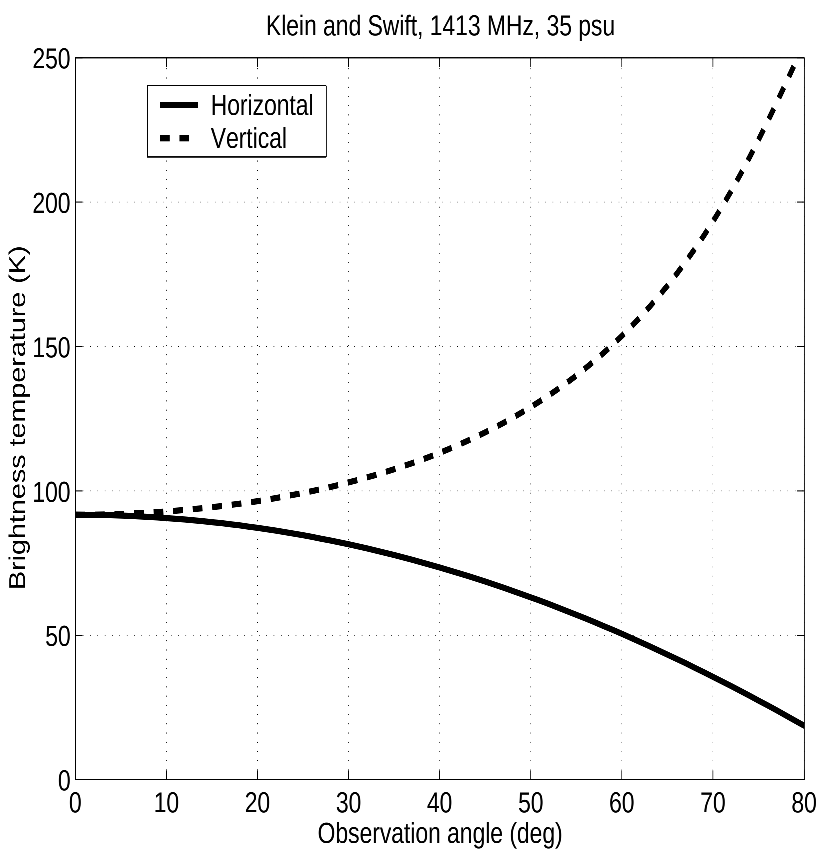

Figure 1: Variations in brightness temperatures with observation angle. $T = 5$ C, $S = 35$ psu, 1413 MHz

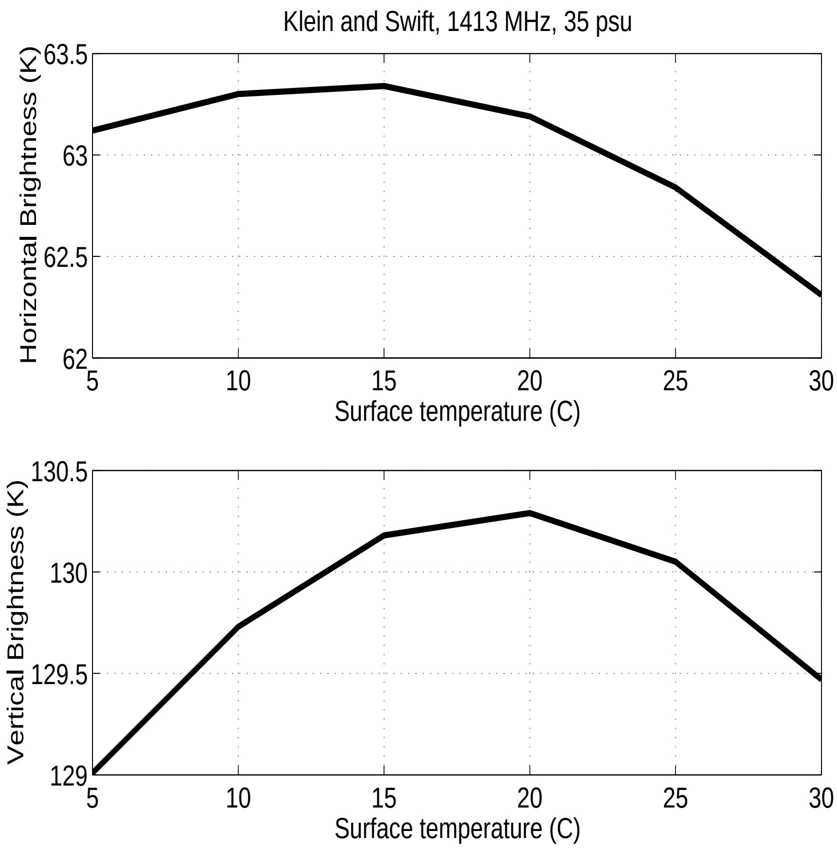

Figure 2: Variations in brightness temperatures with water temperature. 50 degrees, $S = 35$ psu, 1413 MHz

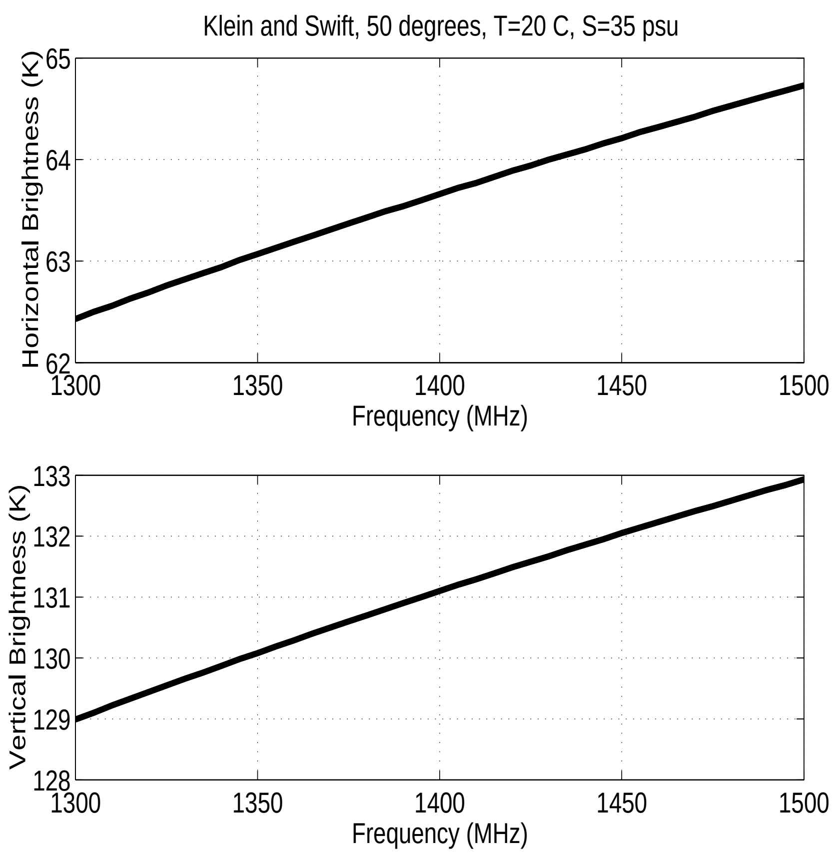

Figure 3: Variations in brightness temperatures with frequency. 50 degrees, $T = 20$ C, $S = 35$ psu

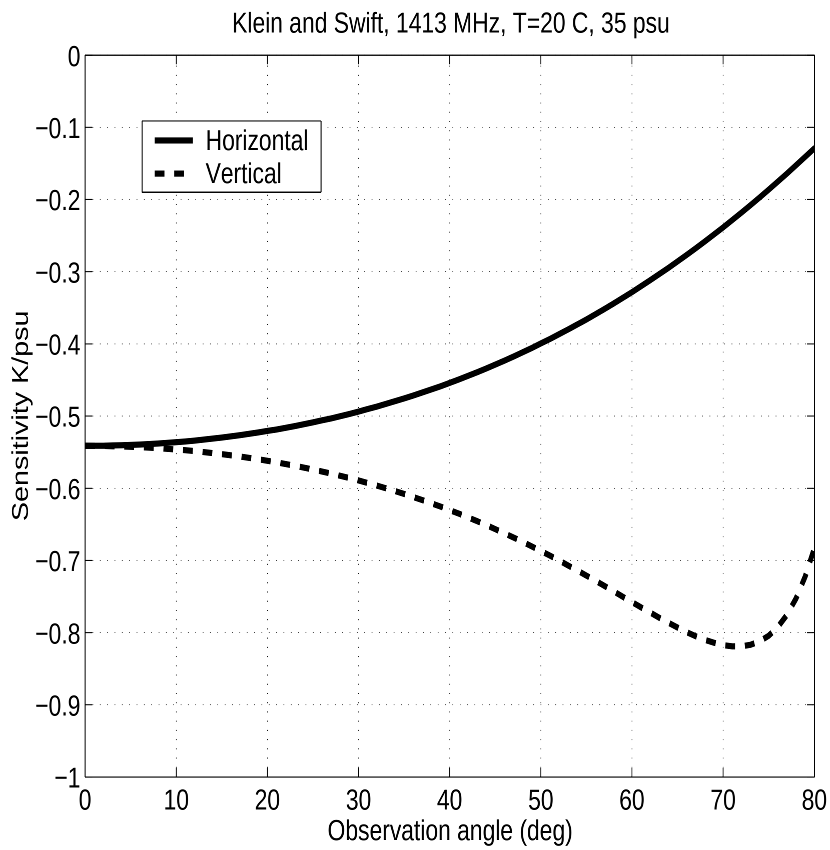

Figure 4: Sensitivity to salinity. 50 degrees, $T = 20$ C, $S = 35$ psu, 1413 MHz

the sensitivity of brightess temperature to salinity (units K/psu) at 1413 MHz for $T = 20$ C, $S = 35$ psu versus observation angle. These are computed through a numerical differentiation of the corresponding brightness temperatures. The result illustrates that vertical polarization is generally more sensitive to salinity variations than horizontal polarization. In both cases, measurements of salinity to within 0.2 to 0.3 psu will require brightness temperature accuracy of 0.1 K or better. Most proposed satellite L-band salinity systems will be polarimetric so that both h and v polarized brightnesses will be obtained.

References

[1] Klein, L. A. and C. T. Swift, "An improved model for the dielectric constant of sea water at microwave frequencies," *IEEE Trans. Ant. Prop.,* vol. AP-25, pp. 104–111, 1977.

[2] Ellison, W., A. Balana, G. Delbos, K. Lamkaouchi, L. Eymard, C. Guillou, and C.

Prigent, “New permittivity measurements of seawater,” *Radio Science,* vol. 33, pp. 639–648, 1998.

[3] Personal communication with W. Wilson, JPL.