Continued External Experiment Plan for IIP Radiometer

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1 Introduction

A previous document [1] described considerations for external experiments with the IIP L-band radiometer. Results showed that operation in the far-field would be possible for observation angles 50 degrees or greater with a 1.2 m aperture antenna located at the 10 m height of the ESL roof. The resulting two-sided beamwidth is approximately 15 degrees, and the 3 dB spot size on the ground is approximately 6×3 m. While the large spot size is unwieldy, reasonable data should still be available from targets that occupy only a portion of the antenna main beam. To make this workable, the antenna should be oriented to observe a fixed location and not moved throughout the duration of the experiments. This will insure that the (large) contributions from regions not of interest remain approximately constant though all measurements, and therefore appear approximately only as an increased receiver noise temperature. Variations in the antenna observation angle may be of interest at some point in the future however, so a mount which can accommodate these variations may be pursued if easily available.

This document further explores measurements of ground targets from the 10 m level of the ESL roof, and describes a procedure by which measurements can be calibrated into brightness values.

2 Building geometry

Figure 1 illustrates the geometry under consideration: a radiometer antenna is located at height h above the 10 m level of the ESL roof. The 7 m level of the roof extends Northward beyond the 10 m level by approximately 6.1 m, and a railing approximately 1 m high is located at the edge of the 7 m roof. Ray tracing analysis allows intersections of the antenna main beam with the roof structure to be determined as a function of the additional antenna height h and the polar observation angle θ. Rays traced in Figure 1 assume a height 2.5 m (8.2 feet) and observation angle 55 degrees with a 15 degree beamwidth, for which the antenna main beam intersects the 7 m railing but not the roof itself. Smaller antenna height or observation angle values result in more of the pattern on the roof, while larger values produce increased spot sizes on the ground. In this case, the resulting 3 dB spot

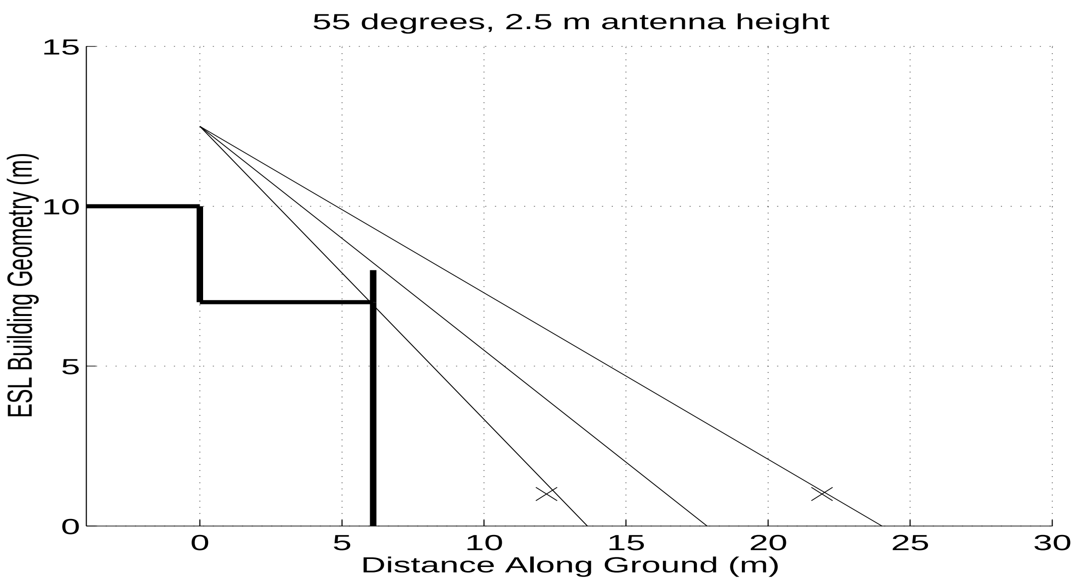

Figure 1: Basic geometry of experiment

size on the ground is approximately 10 m long due to the increased height and observation angle compared to [1]. The "x" symbols marked in the plot indicate the beginning and end locations of the metal portion of the large "horn" antenna in the ESL back-yard.

The large spot size obtained again shows that completely filling this spot with targets of interest will be unwieldy. The procedures following assume that targets are used that fill a large portion of the antenna 3 dB spot (perhaps 20 by 20 feet), but not necessarily the entire area.

3 Calibration targets

To convert measured radiometer voltages into brightness temperatures, at least two calibration targets with known brightnesses are required. The three calibration targets considered here are a microwave absorber, a ground screen to reflect the sky brightness, and a water surface. A discussion of each follows.

3.1 Microwave absorber

Use of microwave absorbers as calibration loads is a standard practice. Under the assumption that the bistatic reflectivity of the absorber is very small for all incident-scattering angle pairs, the absorber is assumed to be a blackbody with a brightness temperature $T_{B,HOT}$ equal to its (usually near ambient) physical temperature:

$$T_{B,HOT} \approx T_{\mathrm{phys,HOT}} \tag{1}$$

$T_{\mathrm{phys,HOT}}$ should be measured with a thermometer of high accuracy, and care should be taken to insure that temperature gradients inside the absorber are not significant. Because the absorber reflectivity is assumed to be minimal, reflections of other environmental brightnesses off the absorber are neglected as well. Of course, absorbers should be chosen that have as small a reflectivity in the band of interest (for both monostatic and bistatic geometries) as possible.

It is also typical to use microwave absorbers heated or cooled to temperatures other than the ambient temperature as calibration sources. A common procedure immerses an absorber in liquid nitrogen to obtain a "cold" absorbing load. However, the large size of the absorbers expected for this experiment would make this impractical. Heating or cooling a large absorber also would be problematic due to thermal gradients that would likely be introduced.

3.2 Ground screen

A large ground screen ideally would produce a brightness equal to the sky brightness temperature T_{sky} integrated over the specularly reflected portion of the antenna pattern. The sky brightness contains contributions from the cosmic microwave background 2.74 K, from celestial sources, and approximately 2 K from the Earth atmosphere [2]. These multiple factors make it difficult to assume that T_{sky} is known precisely, but the work of [2] suggests that it can be predicted to within a few tenths of a Kelvin. The antenna should be oriented to minimize the effects of solar, lunar, and galactic sources if possible to reduce variations in T_{sky}.

A problem with the ground screen calibration target is the possible reflection of other brightness sources near the horizon (trees and building for example.) Define the total brightness when observing the ground screen as T_{refl1}, including both reflected sky and other sources. This quantity will be regarded as unknown in the following presentation due to the potential corrupting terms. A method for determining T_{refl1} will be provided in Section 4.

3.3 Water target

A described in [3], the brightness temperature of a flat water surface can be predicted given its physical temperature $T_{\mathrm{phys,WAT}}$ and salinity S. Use of the water target therefore requires knowledge of the water temperature (measured and recorded as a time series with a highly

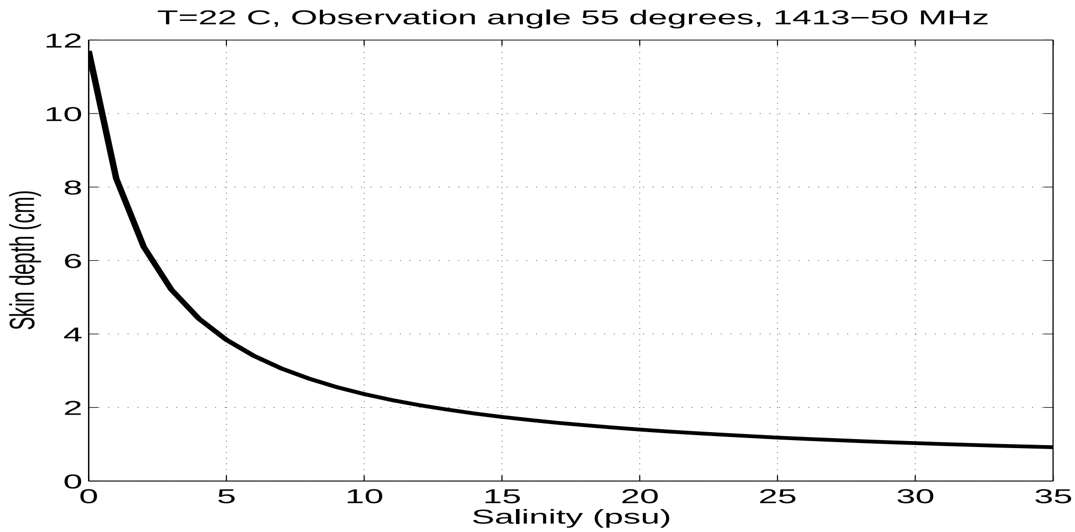

Figure 2: Skin depth of water for $T_{\text{phys,WAT}} = 22$ C, observation angle 55 degrees, and frequency 1363 MHz

accurate thermometer) and salinity (zero for distilled water, can add controlled amounts of salt to vary if needed.) The depth of water in the water target should be greater than at least 4 skin depths at the lowest frequency of interest to insure that a 300 K brightness beneath the pool produces only a 0.1 K contribution to the total brightness. Figure 2 plots the skin depth of water versus salinity for $T_{\text{phys,WAT}} = 22$ C, frequency 1363 MHz (i.e. 1413−50 MHz), and for observation angle 55 degrees, under the water permittivity model described in [3]. To avoid excessive amounts of water, it is recommended that salinities of 15 psu or greater be used, resulting in a water depth of approximately 8 cm (around 3.15 inches.) Fifteen psu implies 15 grams of salt added per kilogram (liter) of distilled water. Alternately local tap water can be used if information on its salinity can be obtained (local water department.) The skin depth is a decreasing function of temperature, and does not exceed 2 cm at salinity 15 psu for temperatures greater than 10 C (around 2.2 cm at 0 C).

The method in [3] describes water surface brightness temperatures for an ideal observing antenna pattern; antenna pattern effects can be estimated by integrating the previous results over a Gaussian pattern in polar observation angle. Figure 3 illustrates brightnesses for horizontal and vertical polarizations versus observation angle when the antenna pattern is included or neglected. Results show the influence of the pattern (15 degree beamwidth) to

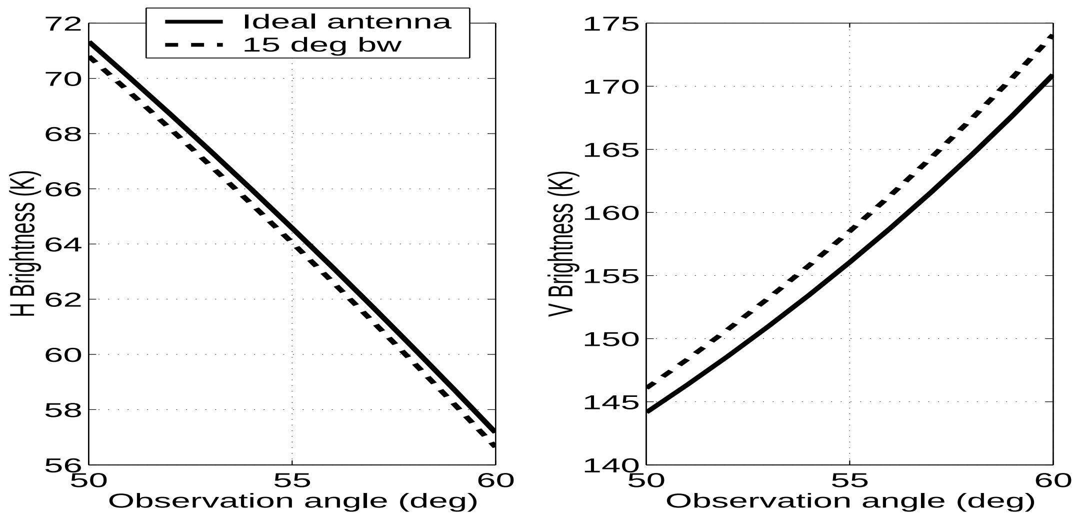

Figure 3: Water surface brightness temperature versus observation angle: effect of antenna pattern. $T_{\text{phys,WAT}} = 22$ C, $S = 15$ psu.

be significant, but less important in horizontal polarization.

Variations in the water surface brightness temperature with reasonable ranges of temperature for a Summer measurement are also of interest. Figure 4 plots brightnesses at 55 degrees observation for salinity 15 psu as a function of water temperature. Results show a strong variation with surface temperature, particularly in vertical polarization, similar to the expected transmissivity times surface temperature dependence. The small transmissivity for horizontal polarization results in less variation with temperature than vertical polarization. Observations of the water brightness as a function of time as the water temperature varies can serve as a test of the calibration procedure. Variations with salinity are plotted in Figure 5, and again show significant variations. Horizontal polarization continues to show smaller effects than vertical polarization.

Again the water target is a reflecting target, so possible reflections of the sky and other brightness sources should be allowed in the calibration procedure. Define these contributions as T_{refl2}. If the water target is chosen to be the same size as the ground screen discussed previously, then the reflected brightness sources will be the same for both the ground screen and water targets. However, the contributions T_{refl1} and T_{refl2} will not be the same due to the differing reflectivities of the two targets. In general there will be no simple relation-

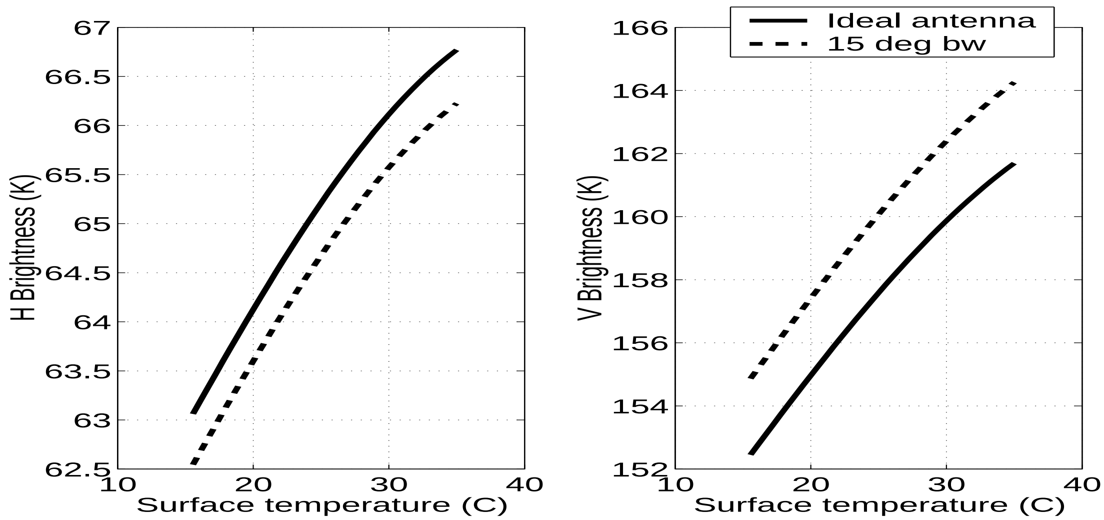

Figure 4: Water surface brightness temperature versus surface temperature: Observation angle 55 degrees, $S = 15$ psu.

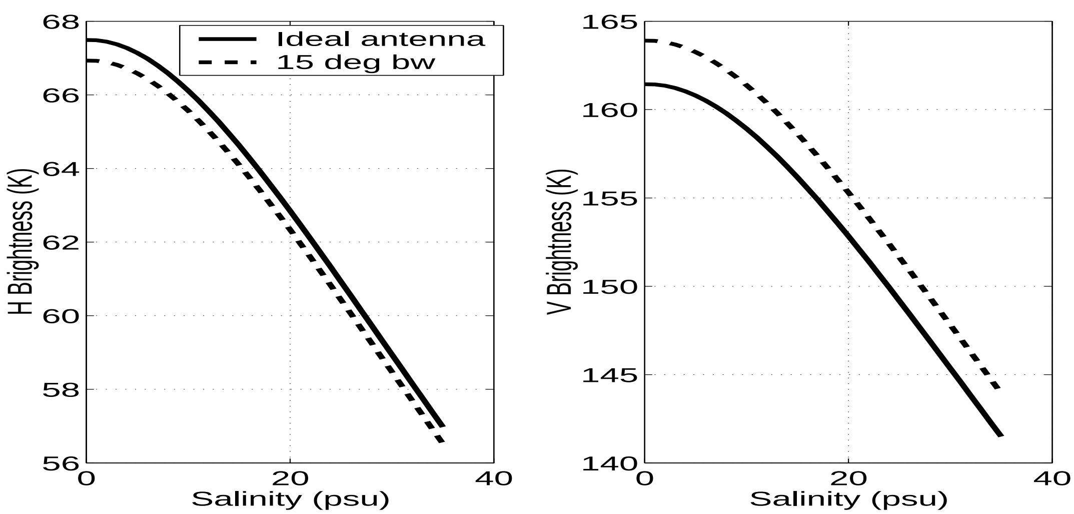

Figure 5: Water surface brightness temperature versus salinity: Observation angle 55 degrees, $T_{\mathrm{phys,WAT}} = 22$ C.

ship between these two because the reflected sources have an unknown distribution in angle, and therefore encounter varying reflectivities off the water surface. However, a simple approximation is often used by assuming that the reflected sources all encounter the specular reflectivity of the target under view. Under this approximation, we assume

$$T_{\text{refl2}} \;=\; |\Gamma|^2 \, T_{\text{refl1}} \tag{2}$$

where Γ is the specular reflection coefficient of the water target under view in the appropriate polarization. Assuming a relationship between T_{refl2} and T_{refl1} is critical for the calibration procedure described in the next section.

4 Calibration procedure

For a linear measurement (i.e. radiometer output voltage linearly proportional to observed brightness), the form of the calibration equation is

$$T_B \;=\; A\,V + B \tag{3}$$

where V is the measured voltage and A and B are the calibration gain and offset, respectively. With the IIP radiometer, these calibration coefficients may also be considered functions of frequency after the FFT operation is performed. Internal calibration standards used to stabilize temporal variations in the A and B coefficients will be important, but are not included here as the current focus is on external effects.

Measurements for the three calibration targets produce the following equations:

$$T_{B,HOT} + T_{\text{junk}} \;=\; A\,V_{HOT} + B \tag{4}$$

$$T_{B,WAT} + T_{\text{refl2}} + T_{\text{junk}} \;=\; A\,V_{WAT} + B \tag{5}$$

$$T_{\text{refl1}} + T_{\text{junk}} \;=\; A\,V_{MET} + B \tag{6}$$

where HOT, WAT, and MET represent the ambient absorbing load, the water surface, and the ground screen targets, respectively. Measurements provide the V_{HOT}, V_{WAT}, and V_{MET} quantities in the above equations, and it is assumed that $T_{B,HOT}$ and $T_{B,WAT}$ are known quantities (approximately, as discussed previously.) The remaining unknowns are T_{junk} (contributions from antenna pattern not on desired target), T_{refl1}, T_{refl2} and the calibration coefficients A and B. If reflected contributions other than the sky brightness can be shown negligible, T_{refl1} will equal the pattern integrated sky brightness which can potentially be considered known as well.

The unknown T_{junk} can be combined with the offset B to create a new offset B':

$$B' \;=\; B - T_{\text{junk}} \tag{7}$$

One of the unknowns is eliminated by this procedure. However it is important to remember that both internal and external effects are present in this offset. To insure that the T_{junk} term is identical in all measurements, all targets (HOT, WAT, and MET) should be made of identical sizes and shapes. While temporal variations in the internal (B) component of the new offset B' can likely be compensated by internal calibration standards, the external component T_{junk} may also vary with time as the ambient temperature changes. Time series observations will hopefully help to quantify this influence.

With the introduction of B', there remain four unknowns with only three equations. The approximate relationship between T_{refl1} and T_{refl2} introduced in equation (2) provides the final equation, and results in the system:

$$
\begin{aligned}
T_{B,HOT} &= A\,V_{HOT} + B' && (8)\\
T_{B,WAT} + T_{\text{refl2}} &= A\,V_{WAT} + B' && (9)\\
T_{\text{refl1}} &= A\,V_{MET} + B' && (10)\\
T_{\text{refl2}} &= QT_{\text{refl1}} && (11)
\end{aligned}
$$

The symbol Q is introduced in the final equation to be less specific about the relationship between the two reflected contributions.

Solving this system produces:

$$
\begin{aligned}
A &= \frac{T_{B,WAT} + (Q-1)T_{B,HOT}}{V_{WAT} + (Q-1)V_{HOT} - QV_{MET}} && (12)\\
B' &= T_{B,HOT} - AV_{HOT} && (13)
\end{aligned}
$$

Note if $Q = 0$ the procedure uses only the water surface and ambient absorbing load targets for calibration.

5 Discussion

The above procedure provides knowledge of the gain and offset parameters A and B', and enables computation of the brightness of additional targets not included in the calibration. For the calibration targets, this procedure will result in exactly their predicted brightnesses by definition. However, all of the targets planned for observation in the experiments are included in the calibration: how can any unknown information be obtained from this process? A time series of observations will be required to address this issue. Because the water surface brightness will vary with the ambient temperature (and recorded water surface temperature), a new target will be available with each appreciable temperature change. The ambient absorbing load can provide a similar time series, and in fact should be a better standard since reflected contributions are minimal. Issues with this process are:

- Receiver stability will be critical in these measurements. Internal calibration standards will be very important to allow internal variations to be of minimal importance relative to external temporal variations. Required time scales for maintaining stability are on the order of hours, if not days.

- Variations of T_{junk}, T_{refl1}, and T_{refl2} with the ambient temperature are possible, and will confuse the time series observations. Careful data processing will be needed to distinguish these effects. Comparison of T_{refl1} with expected sky brightnesses may help here.

- The assumed simple relationship between T_{refl1} and T_{refl2} may not be sufficiently accurate to provide precise calibration. Again data will be needed to assess this; keeping the horizon as clear as possible for the reflected antenna pattern will help.

- The water surface brightness model may not be of sufficient accuracy, as it is based only on a limited series of measurements. A large data set will help provide insight again.

- The ambient absorbing load should have as minimal a reflectivity as possible.

- Having observations in both horizontal and vertical polarizations (switched frequently in time) will provide more information to assist in interpreting time series data.

Materials that will be needed include an antenna mount, at least two precision thermometers capable of recording a time series of observations, a ground screen, a large sheet of L-band absorber, and the water pool. The calibration targets should all be on the order of at least 20 x 20 feet. Once the antenna is mounted, a series of tests will be required to locate the qualitatively map the antenna pattern; an active system can be used for this process if desired.

References

[1] Johnson, J. T., "Initial external experiment plan for IIP radiometer," Internal report, 2002.

[2] Delahaye, J., P. Gole, and P. Waldteufel, "Calibration error of L-band sky-looking ground-based radiometers," *Radio Science,* vol. 37, pp. 11(1)-11(11), 2002.

[3] Johnson, J. T., "Brightness temperature of a flat water surface," Internal report, 2002.