Problem 1

(a) A microwave radiometer operates in a 10 MHz bandwidth centered at 2695 MHz. The radiometer receiver has a 3 dB noise figure. Find the noise equivalent delta temperature (NEDT) that corresponds to a 10 msec integration period for this radiometer if (i) a 290K scene is observed and (ii) a 100 K scene is observed.

(b) The radiometer is calibrated by using “hot” and “cold” loads of known brightness temperature. The power $P$ measured from these targets follows the equation $P = A T_B + B$, where $A$ and $B$ are “gain” and “offset” parameters to be determined by the calibration. Given measurements $P_{hot}$ and $P_{cold}$ corresponding to known $T_{B,hot}$ and $T_{B,cold}$, derive equations to determine $A$ and $B$.

(c) Measurement errors associated with NEDT impact the calibration process. Perform a Monte Carlo simulation of radiometer calibration and observations including NEDT. You will need to model individual hot and cold load observations as samples of a Gaussian random variable with standard deviation NEDT. The Monte Carlo simulation involves generating many trials of NEDT corrupted hot and cold load measurements; each pair of hot and cold samples produces a sample of $A$ and $B$ using your part (b) solution.

The final step involves applying these corrupted $A$ and $B$ coefficients to calibrate an observation of a scene of specified brightness temperature; again many trials of the calibrated observation can be produced, and the resulting error examined.

Perform the simulation for the following “truth” parameters and compare the errors that result for the final scene brightness to NEDT:

(i) $(T_{B,hot}, P_{hot}) = (300K, 1.5), (T_{B,cold}, P_{cold}) = (77K, 0.7567), T_{B,scene} = 290K$.

(ii) $(T_{B,hot}, P_{hot}) = (300K, 1.5), (T_{B,cold}, P_{cold}) = (77K, 0.7567), T_{B,scene} = 100K$.

(iii) $(T_{B,hot}, P_{hot}) = (300K, 1.5), (T_{B,cold}, P_{cold}) = (250K, 1.333), T_{B,scene} = 290K$.

(iv) $(T_{B,hot}, P_{hot}) = (300K, 1.5), (T_{B,cold}, P_{cold}) = (250K, 1.333), T_{B,scene} = 100K$.

(d) Can you draw any conclusions from these results regarding the selection of desirable targets to serve as “hot” and “cold” loads? How could the influence of calibration errors be reduced?
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Problem 2
An unusual atmospheric condition arises so that the specific attenuation in Np/km near frequency $f_0 = 22.235$ GHz is

$$\alpha(f, z) = \frac{1}{(z + 2) f_0} \left(\frac{f}{f_0}\right)^2 \frac{9}{(f - f_0)^2 + 9} \quad 0 < z < 8$$

where $f$ is the frequency in GHz ($f_0$ is also in GHz) and $z$ is the altitude in km. There is no additional specific attenuation at altitudes greater than 8 km.

(a) Find $\tau(f, z') = \int_z^{z'} \alpha(f, z) dz$ (the optical depth from altitude $z'$ to the top of the atmosphere) and plot for $f=15$ to 30 GHz with $z' = 0$.

(b) Find the weighting functions $W(z, \theta, f)$ that correspond to this atmosphere. Plot the weighting functions vs altitude $z$ from 0 to 8 km for $\theta = 0^\circ$ and $f=16, 18, \ldots, 24$ GHz. Interpret your results. Do you think temperature profile retrieval would be possible in this situation?

(c) For a constant atmospheric temperature of 273 K from 0 to 8 km, find the brightness temperature of the atmosphere as a function of $\theta$ and $f$ (can be determined analytically in this special case). Plot the brightness temperature vs. $\theta$ for $f=16, 18, \ldots, 24$ GHz.

(d) Interpret your results. Which frequencies and angles have higher brightness temperatures? Why?

Problem 3
This problem makes use of the Matlab functions soil_eps.m, sea_eps.m, and flatsurface_tb.m on the course website (note these have been updated recently, previous versions should not be used.) Consider a radiometer operating at 1.413 GHz (as for the SMAP, SMOS, and Aquarius missions).

(a) Plot the brightness temperature of a flat soil surface vs. soil moisture from 0 to 40% in vertical and horizontal polarizations for $\theta = 0^\circ$. Assume a surface physical temperature of 293 K, and use other nominal parameters from the lecture slides.

(b) Repeat part (a) for $\theta = 15^\circ$, $\theta = 30^\circ$, and $\theta = 45^\circ$. Discuss the sensitivity of the brightness temperature to soil moisture as a function of angle and polarization. Which case would be most desirable for passive sensing of soil moisture? Note SMAP uses $\theta = 40^\circ$.

(c) Plot the brightness temperature of a flat sea surface vs. salinity from 20 to 40 psu in vertical and horizontal polarizations for $\theta = 0^\circ$. Assume a surface physical temperature of 293 K.

(d) Repeat part (c) for $\theta = 15^\circ$, $\theta = 30^\circ$, and $\theta = 45^\circ$. Discuss the sensitivity of the brightness temperature to salinity as a function of angle and polarization. Which case would be most desirable for passive sensing of salinity? Note Aquarius uses three angles: 28.7, 37.8, and 45.6 degrees.
Problem 4
In this problem we will consider SMAP radiometer observations of vegetation-covered soil surfaces using the tau-omega model. SMAP operates at 1.413 GHz and $\theta = 40^\circ$, and has an NEDT of approximately 1K. Assume that the $b$ and $\Omega$ vegetation parameters are both 0.1, and that the surface and vegetation physical temperature are both 293 K. Other soil parameters from the lecture slides can be used. The function tau_omega_tb.m is available on the course website to simplify the computations.

(a) Plot the brightness temperature in vertical and horizontal polarizations versus soil moisture for vegetation water contents 0, 5, and 10 kg/square meter.
(b) Find the change in brightness temperature that corresponds to a change in soil moisture from 6% to 10% for each of the vegetation water contents.
(c) If it is desired to measure a 4% change in soil moisture (as in part (b)), discuss any limitations with regard to the vegetation water content.