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RADIOMETER SYSTEM REQUIREMENTS FOR MICROWAVE REMOTE SENSING FROM SATELLITES

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An area of increasing interest for the Antenna and Microwave Research Branch is the establishment of a significant research program in microwave remote sensing from satellites, particularly geosynchronous satellites. Due to the relatively small resolution cell sizes, a severe requirement is placed on the "beam efficiency" specifications for the radiometer antenna.

Geostationary satellite microwave radiometers could continuously monitor several important geophysical parameters over the world's oceans. These parameters include the columnar content of atmospheric liquid water (both cloud and rain) and water vapor, air temperature profiles, and possibly sea surface temperature.

Two principle features of performance are of concern for this study. The first is the ability of the radiometer system to resolve absolute temperatures with a very small absolute error, a capability that depends on radiometer system stability, on frequency bandwidth, and on footprint dwell time. The second is the ability of the radiometer to resolve changes in temperature from one resolution cell to the next when these temperatures are subject to wide variation over the overall field-of-view of the instrument. Both of these features are involved in the use of the radiometer data to construct high-resolution temperature maps with high absolute accuracy.

The pulsewidth or sea state (depending on which represents the larger time spread to the altimeter) determines the footprint size. This footprint acts as a spatial filter that has to be considered in detecting surface features. Its minimum radius is calculated as follows:

$$r = (hcT)^{1/2}$$

where h = satellite height, c = speed of light, T = pulsewidth.

A simple (first-order only) model of the return waveforms can be based on physical-optics scattering theory. The illuminated surface area determines the reflected radar power as the pulse impinges on the earth's spherical surface. This backscattered power (on the average) increases until the whole pulse has reached the surface.

Every object with a physical temperature above absolute zero ($0°K$ = $-273°C$) radiates energy. The amount of energy radiated is usually represented by a brightness temperature T_B and it is defined as

$$T_B(\theta,\phi) = \varepsilon(\theta,\phi)T_m = (1-|\Gamma|^2)T_m$$

where

T_B = brightness temperature (equivalent temperature; ^oK),
ε = emissivity (dimensionless),
T_m = molecular (physical) temperature (^oK),
$\Gamma(\theta, \phi)$ = reflection coefficient of the surface for the polarization of the wave.

The brightness temperature emitted by the different sources is intercepted by antennas, and it appears at their terminals as an antenna temperature. The temperature appearing at the terminal of an antenna is weighted by the gain pattern of the antenna. This can be written as

$$T_A = \frac{\int_0^{2\pi}\int_0^{\pi} T_B(\theta,\phi)G(\theta,\phi)\sin(\theta)d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi} G(\theta,\phi)\sin(\theta)d\theta d\phi}$$

where

T_A = antenna temperature (effective noise temperature of the antenna radiation resistance; ^oK),
$G(\theta, \phi)$ = gain (power) pattern of the antenna.

If no mismatch losses and a lossless transmission line between the antenna and the receiver, the noise power transferred to the receiver is given by

$$P_r = KT_A \Delta f$$

where

P_r = Antenna noise power (W),
K = Boltzmann's constant (1.38 E-23 J/^oK),
T_A = antenna temperature (^oK),
Δf = bandwidth (Hz).

If the transmission line losses between the antenna and receiver must be considered, the antenna temperature T_A has to be modified to include the line losses. The effective antenna temperature at the receiver terminals is given by

$$T_a = T_A e^{-2\alpha l} + T_o(1 - e^{-2\alpha l})$$

where
T_a = antenna temperature at the receiver terminals (^oK),
T_A = antenna temperature at the antenna terminals (^oK),
α = attenuation coefficient of the transmission line (Np/m),
l = length of transmission line (m),
T_o = physical temperature of the transmission line (^oK).

The antenna noise power must has a certain noise temperature T_r (due to thermal noise in the receiver components), the system noise power at the receiver terminals is given by

$$P_s = K(T_a + T_r)\Delta f = KT_s\Delta f$$

From the receiving equipment, the antenna is a source of useful signal and also a unwanted noise caused by radioemission from the Galaxy, atmosphere, Earth, local objects, and the antenna elements themselves. The noise temperature of a network is the temperature of the output resistance that provides the same noise power which received from the network. The noise power output of an antenna can be characterized by the antenna noise temperature, T_{na}. The antenna noise temperature can be obtained from the equation as follows:

$$T_{na} = \overline{T}_m + \overline{T}_s\beta\eta + T_o(1-\eta)$$

with

$$\overline{T}_m = \frac{\int_{\Omega_m} T(\theta,\phi)F(\theta,\phi)d\Omega}{\int_{\Omega_m} F(\theta,\phi)d\Omega} \quad , \quad \overline{T}_s = \frac{\int_{\Omega_s} T(\theta,\phi)F(\theta,\phi)d\Omega}{\int_{\Omega_s} F(\theta,\phi)d\Omega}$$

where

T_m = the average background brightness temperature for the antenna main lobe,
T_s = the average background brightness temperature for the antenna side lobe,
T_o = temperature of the surrounding medium (^oK),
β = the antenna stray factor,
η = the radiation efficiency,
$F(\phi,\theta)$ = an antenna pattern function.

From the system noise power the equation becomes

$$\begin{aligned} P_s &= KT_s\Delta f = K(T_a + T_r)\Delta f \\ &= K\Delta f\left[T_A e^{-2\alpha l} + T_o(1-e^{-2\alpha l}) + T_r\right] \\ &\approx K\Delta f\, T_A e^{-2\alpha l} \end{aligned}$$

By the Fourier transforms and Bessel functions, the antenna noise temperature equation can be solved. This result can then be used to produce a computer program that can accept input "temperature-contrast" maps.