Brightness Temperature from Very Lossy Medium

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***Abstract*—The brightness temperature from moistured soil with a flat surface is computed by defining near-field bistatic transmission coefficients (BTCs) and modifying the Planck's law for lossy medium. The efficacy of the proposed methods are verified by simulations and comparison with literatures.**

***Keywords*—brightness temperature, moistured soil, bistatic transmission coefficient, finite-difference time-domain method.**

I. Introduction

In microwave passive remote sensing, the brightness temperature measured with radiometers is proportional to the specific intensity emitted from the ground [1]. In the Soil Moisture and Ocean Salinity (SMOS) mission, the brightness temperature was measured with an L-band interferometric radiometer to estimate the global soil moisture [2]. The Soil Moisture Active and Passive (SMAP) mission was conducted to collect information on global soil moisture, which significantly affects hydrology, meteorology and agriculture [3]. In microwave spectrum, the Rayleigh-Jeans approximation relates specific intensity to the physical temperature and surface emissivity [4].

Conventionally, bistatic transmission coefficients (BTCs) are the ratio of transmitted specific intensity above ground surface to the incident specific intensity just beneath ground surface [5]. Conventional BTCs and bistatic scattering coefficients (BSCs) are defined in terms of the far fields [1]. These coefficients work fine in lossless and low-loss media. In a lossy medium, the transmitted far fields approach zero, the BTCs thus defined will be zero.

In this work, near-field BTCs are defined in terms of variables right on the surface, and the boundary conditions on specific intensities can be expressed in terms of these near-field BTCs. The Planck's law is modified by differentiating group velocity and phase velocity. The finite-difference time-domain (FDTD) method is applied to compute near-field BTCs from a very lossy medium with flat surface. In conjunction with the modified Planck's law, the brightness temperatures are computed and compared with literatures.

II. Near-Field BTCs

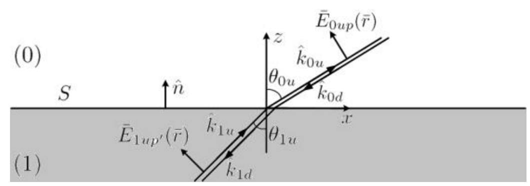

Fig. 1. Scattering of fields from moistured soil in region (1) to air in region (0), via a flat surface.

Fig.1 shows a flat surface between a lossy moistured soil and air. The scattering of fields from region (1) to region (0) can be characterized by a near-field BTC as

$$\zeta^{01}_{pp'}(\hat{k}_{0u}, k_{1u}) = \frac{K_{0up}(\hat{k}_{0u})}{K_{1up'}(\hat{k}_{1u})}$$

where $K_{0up}(\hat{k}_{0u})$ (in unit Wm^2) is called the transmitted power strength of p-polarization ($p = h, v$) in the direction $\hat{k}_{0u}$, which is defined in terms of the two-dimensional Fourier transforms of the equivalent electric surface currents $\bar{J}_{e0u}$ and magnetic surface current $\bar{M}_{e0u}$ on a Huygens' surface above the surface S between regions (0) and (1).

The conventional BTC from region (1) to region (0) is defined as $\xi^{01}_{pp'}(\hat{k}_{0u}, k_{1u}) = \dfrac{4\pi r_0^2 I_{0up}(\hat{k}_{0u})}{P_{1up'}(\hat{k}_{1u})}$,

where $I_{0up}(\hat{k}_{0u}) = \mathrm{Re}\{\bar{E}_{0up}(\bar{r}_0) \times \bar{H}^*_{0up'}(\bar{r}_0)\} \cdot k_{0u} / 2$ is the far-field transmitted power density at $\bar{r}_0 = \hat{k}_{0u} r_0$. If S is a flat surface, conventional and the near-field BTCs are related as $\xi^{01}_{pp'}(\hat{k}_{0u}, k_{1u}) = \dfrac{k_0^2 \cos\theta_{1u} A_g^2}{\pi X_b Y_b} \zeta^{01}_{pp'}(\hat{k}_{0u}, k_{1u})$, where $A_g = L_x L_y$ is the surface area in the computational domain.

III. Boundary Condition in Terms of Near-Field BTCs

The boundary condition on S can be represented in terms of power strengths as

$$\frac{A_g \cos\theta_{0u}}{F_c r_0^2} K_{0up}(\hat{k}_{0u}) = \iint d\Omega_{1u} \frac{A_g}{X_b Y_b} \left[\zeta^{01}_{pp}(\hat{k}_{0u}, k_{1u}) K_{1up}(\hat{k}_{1u}) + \zeta^{01}_{pp'}(k_{0u}, \hat{k}_{1u}) K_{1up'}(k_{1u}) \right]$$

which is reduced to the conventional boundary condition in terms of specific intensities as

$$\cos\theta_{0u} I_{0up}^{(0)}(\hat{k}_{0u}) = \frac{1}{4\pi}\iint d\Omega_{1u}\cos\theta_{1u}$$
$$\left[\xi_{pp}^{01}(\hat{k}_{0u}, k_{1u}) I_{1up}^{(0)}(\hat{k}_{0u}) + \xi_{pp'}^{01}(k_{0u}, \hat{k}_{1u}) I_{1up'}^{(0)}(k_{1u})\right]$$

The blackbody radiation intensity was originally derived in a lossless medium. The specific intensity is proportional to the energy density multiplied by the phase velocity. In a lossy medium, the specific intensity should be the energy density multiplied by the group velocity, namely,

$$I_\nu = \frac{\kappa T}{2\pi^2\omega^2\mu_0}\frac{k'^3(k'^2 + k''^2)}{\varepsilon_m' k' + \varepsilon_m'' k''}$$

which is the modified Rayleigh-Jeans approximation. If region (1) is lossless and S is a flat surface, the boundary condition reduces to

$$\frac{T_{bp0}(\hat{k}_{0u})}{T_1} = \frac{1}{4\pi}\iint d\Omega_{1u}\left[\xi_{pp}^{10}(-\hat{k}_{0u}, -k_{1u}) + \xi_{pp'}^{10}(-\hat{k}_{0u}, -k_{1u})\right]$$

which is the conventional formula to calculate the brightness temperature attributed to region (1).

IV. Simulations and Discussions

In the simulations, the near-field BTCs are computed by using the FDTD method with tapered incident fields. Fig.2 shows the brightness temperatures from a lossy medium with a flat surface. The frequency of incident field is $f_c = 1.4$ GHz (λ = 21.43 cm). The dielectric constant in region (1) is $\varepsilon_{r1} = 17 - j2$, leading to an effective conductivity of σ_1 = 0.1558 S/m and a skin depth of δ_1 = 0.0341 m. The effective wavelength in region (1) is about $\lambda_1 = \lambda/\sqrt{\varepsilon_{r1}'}$ = 0.24 λ. The spatial interval in the FDTD scheme is chosen as Δx = 0.05 λ_1 = 0.012 λ = 0.0026 m. The surface size is chosen as $L_x = L_y = 8\lambda$.

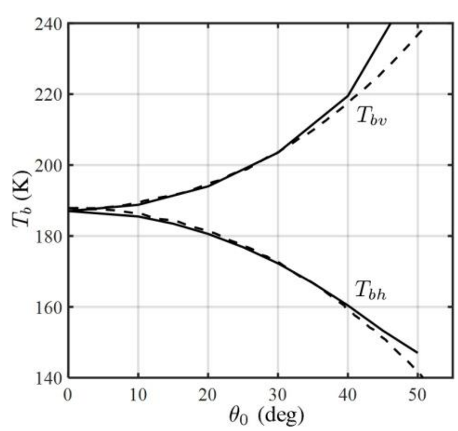

Fig. 2. Brightness temperatures from a lossy medium of $\varepsilon_r = 17 - j2$, with a flat surface; solid curves: this approach, dashed curves: [6].

The errors of brightness temperatures are less than 1 K for $\theta_0 < 40^\circ$ and around 5 K at $\theta_0 = 50^\circ$. The predictions with our approach agree reasonably well with those in [6].

V. Conclusion

In this work, a rigorous new approach is proposed to predict the brightness temperatures from a very lossy half space, by defining near-field BTCs and modifying the Planck's law. Simulation results with the FDTD method have verified the efficacy of this approach.

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