1. A current density due to flow of free charges is given by $\boldsymbol{J} = -(5x\, \boldsymbol{a}_x + 2y\, \boldsymbol{a}_y + z^2\, \boldsymbol{a}_z)$.
   (1) By using surface integrals directly, find the **displacement current** emanating from the closed surface of the cubic box bounded by the planes $x = \pm 1,\ y = \pm 1,\ z = \pm 1$. (5%)
   (2) Redo (1) by using an appropriate volume integral. (5%)

2. As shown in Fig. 1, a system with two parallel square conducting plates, each having an area S, is to be analyzed. The space between two parallel square conducting plates is filled with two different lossy dielectrics, of which the thicknesses d_1, $d_2 << S^{1/2}=l$ (the length) so that the fringe effect can be neglected. A battery of dc voltage V is applied across the plates.
   (1) Find the steady current densities in both dielectrics (5%)
   (2) Find the surface charge densities on the interfaces. Please explain briefly their origin. (5%)
   (3) Find the resistance of the system. (5%)

3. As shown in Fig. 1, the dielectric 1 is lossless, i.e., $\sigma_1=0$.
   (1) Find the potential on the interface between dielectrics 1 & 2, i.e., $x=d_2$. (5%)
   (2) Find the electric force $\boldsymbol{F}_e$ for the dielectric 1 (ε_1, μ_1) in the situation shown as the dashed square in Fig. 1. (5%)

4. As shown in Fig. 1, the dielectrics 1 and 2 are lossless, i.e., $\sigma_1=\sigma_2=0$.
   (1) Please find the capacitance of the system. (5%)
   (2) If the voltage source V is changed to a current source I and short-circuited at the other end, please find the external inductance (i.e., contribution from the flux in the gap) L_e of the system. (5%)
   (3) Continued from (3), if both conducting plates are of finite (ε, σ, μ) and thickness d ($d << S^{1/2}=l$), please find the internal inductance L_i (i.e., contribution from the flux in the conductor) of the system. (5%)

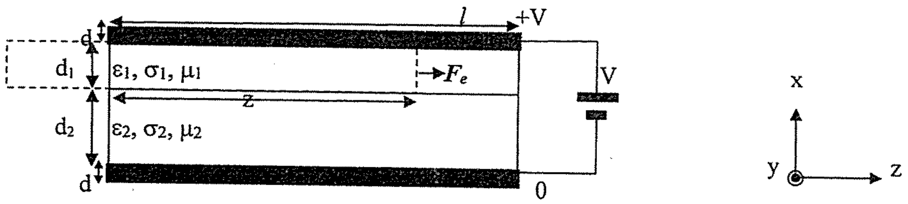

Fig. 1 The system diagram for Problems 2-4

5. Consider an electromagnetic wave, $(\overline{E}, \overline{H})$, propagation in free space. Let $\overline{E} = (E_x, E_y, E_z)$ and $\overline{H} = (H_x, H_y, H_z)$, where $E_z = 0$.
   (1) If the field dependences on time, t, and z are $e^{j\omega t}$ and $e^{-j\beta_z z}$, respectively, please find the ratios of $\eta_{xy} = E_x / H_y$ and $\eta_{yx} = E_y / H_x$. (Hint: Use Maxwell's equations $\nabla \times \overline{E} = -\mu_0 \dfrac{\partial \overline{H}}{\partial t}$ and $\nabla \times \overline{H} = \varepsilon_0 \dfrac{\partial \overline{E}}{\partial t}$) (5%)
   (2) In (1), show $\eta_{xy} = -\eta_{yx} \cong 377$ when $\beta_z \to \omega\sqrt{\mu_0 \varepsilon_0}$. ($Z_o \cong 377\Omega$ is the intrinsic impedance of free space.) (5%)
   (3) In (1), if the dependences on x and y are $e^{-j\beta_x x}$ and $e^{-j\beta_y y}$, respectively, please show $\beta_x^2 + \beta_y^2 + \beta_z^2 = \omega^2 \mu_0 \varepsilon_0$. (5%)

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6. Consider a section of parallel-plate waveguide with perfect conducting plates located at $x=0$ and $x=a$. The medium inside the waveguide is air.
   (1) If $a=5$ cm, please find the cutoff frequencies and their associated cutoff wavelengths for the lowest **three** TE modes. (5%)
   (2) In practical applications, the waveguide is operated at the lowest fundamental mode, please find the **frequency bandwidth** for this waveguide. (3%)
   (3) Now consider a second section of parallel-plate waveguide of the same size ($a=5$) with the medium changed to dielectric materials of $\varepsilon_r=2.25$. This section and the one in (a) are connected as shown in Fig. 2 below. Again the fundamental mode operation is assumed. Please find the **frequency bandwidth**. (5%)
   (4) In Fig. 2, what is the requirement of **dielectric constant** ε_r if the reduction of bandwidth is less than 30% ? Please explain your argument. (5%)
   (5) Find the guide **characteristic impedances,** η_{g1} and η_{g2}, for these two waveguides. Please also find the **reflection and transmission coefficients** at the junction. (5%)

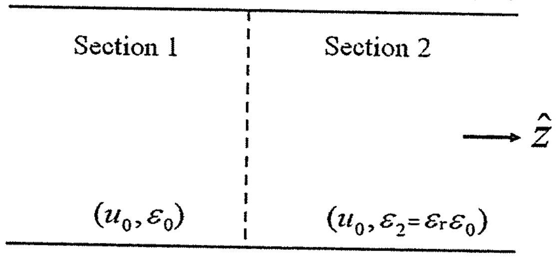

Fig. 2: The transmission lines diagram for problem 6.

7. Consider a transmission line with a characteristic impedance, Z_0, which is terminated by an arbitrary load, Z_L as illustrated in Fig. 3. The propagation constant is β. One considers the wave propagation voltage, $V(d)$ and current $I(d)$ along the transmission line. The voltage reflection coefficient at $d=0$ is Γ_L. In particular, $V(d)$ can be expressed as $V(d)=V^+(e^{j\beta d}+\Gamma_L e^{-j\beta d})$.
   (1) Find the corresponding **current distribution**, $I(d)$, and find the **separation distance** between the two maximums of $I(d)$ in terms of wavelength λ in the formed standing wave pattern? What is the **period** of standing wave pattern? (Note: $\beta=2\pi/\lambda$) (4%)
   (2) In (1), please find **separation distance** between the adjacent maximums of $V(d)$ and $I(d)$? Explain your argument. (4%)
   (3) Express the **SWR (standing wave ratio)** in terms of Γ_L. In practical application, -10dB reflection coefficient ($|\Gamma_L|=0.316$) is used as a threshold to justify the bandwidth of RF system. Please find the corresponding **SWR**. If SWR=1.5 is considered as the new threshold, what is the corresponding **reflection coefficient** $|\Gamma_L|$? (4%)

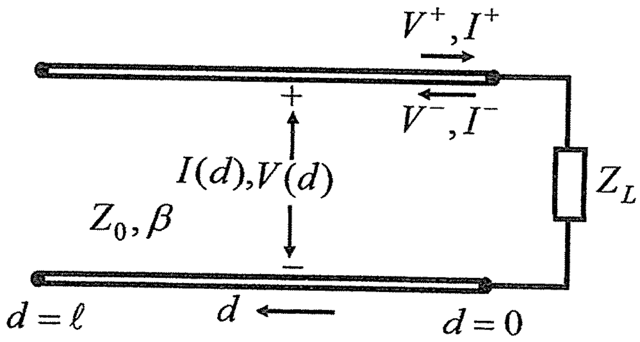

Fig. 3: The circuit of transmission line for Problem 7.

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