§7. Hybrid Alfvén Resonant Mode Generation in the Magnetosphere-ionosphere Coupling System


Feedback unstable Alfvén waves involving global field-line oscillations and the ionospheric Alfvén resonator (IAR) were comprehensively studied to clarify their properties of frequency dispersion, growth rate, and eigenfunctions. As an extended study of our previous works, linear eigenmodes of ionospheric feedback instability in the dipole magnetic field ($B_0$) geometry were analyzed by considering the ionospheric and magnetospheric resonant cavities of the Alfvén velocity ($v_A$). The two-field reduced magnetohydrodynamic model,

\[ \frac{\partial}{\partial t} \psi + v_0 \cdot \nabla \psi + \frac{1}{B_0} \nabla B_0 \phi = 0, \]

is used to describe shear Alfvén wave dynamics, associated with auroral arcs, in a strongly non-uniform magnetic flux tube; see our paper\(^1\) for definition of these variables.

These equations are coupled with the two-fluid equations in the ionosphere as,

\[ \frac{\partial}{\partial t} n_e + v_0 \cdot \nabla n_e = j || - R n_e \]

\[ -\alpha \nabla^2 \phi + (\mu \nu E_0 - v_0) \cdot \nabla n_e = D \nabla^2 n_e - j || \]

yielding the linear dispersion relation for feedback instability; see our paper\(^1\) for definition of these variables. Equations (1)–(4) are solved to obtain the eigenfrequency and eigenfunctions of Alfvén waves shown in Figs. 1 and 2.

This study\(^2\) discovered that a new mode called here the hybrid Alfvén resonant (HAR) mode can be destabilized in the magnetosphere-ionosphere coupling system with a realistic $v_A$. The HAR mode found in a high frequency range over 0.3 Hz is caused by coupling of IAR modes (0.5, 1 Hz, . . . ) with strong dispersion and field line resonances (FLR). The harmonic relation of HAR eigenfrequencies is characterized by a constant frequency shift from those of IAR modes. The three modes (FLR, IAR, and HAR) are robustly found even if effects of two-fluid process and ionospheric collision are taken into account, and thus are anticipated to be detected by magnetic field observations in auroral and polar-cap regions.


Fig. 1: (a) Alfvén velocity profiles $v_A(s)$ used in this analysis. (b) The maximum growth rate $\gamma_{\max}(n)\tau_A/\pi$ as a function of harmonic number $n$; $\gamma \equiv \text{Im}(\Omega)$ with the Alfvén transit time $\tau_A$.

Fig. 2: (a) Real part of eigenfrequency $\text{Re}(\Omega)\tau_A/\pi$ as a function of electric drift frequency $\sigma$ for $v_A$ profile f in Fig. 1. The harmonics $n = 0$–80 are shown. Shown are eigenfunctions $\text{Im}(B_0\psi)$ of (b) IAR ($n = 29, 53,$ and 77) and (c) HAR ($n = 18, 42,$ and 66) modes providing $\gamma_{\max}(n)$.