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Development of Capacitively-Coupled Combline Antennas for Current Drive in Tokamaks

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The capacitively-coupled combline (CCC) antenna has been developed for current drive by the lower hybrid wave (LHW) on the TST-2 spherical tokamak. In order to excite a highly directional wave required for efficient current drive, an antenna array consisting of many elements is necessary, but it is impractical to feed each of these elements independently in a device with limited accessibility. The combline antenna was developed to satisfy the requirements of high directionality, low reflectivity, and simple feeding. Since the combline antenna makes use of mutual coupling between neighboring elements, only the first and the last elements are connected to external feedlines. Each element is an L-C resonant circuit, coupled to neighboring elements by mutual capacitance, and exhibits a passband characteristic. The copper capacitive elements are shaped so that the RF electric field extends well into the plasma. The inductive elements are covered so neighboring elements do not couple inductively to each other and the RF magnetic field does not extend into the plasma. Faraday shield is not necessary. RF powers and power densities of the order of 100 kW and 1 MW/m ^{2} can be achieved easily in small antennas of the order of 0.1 m^2, because of the inherently low standing wave ratio. The two CCC antennas installed in TST-2 (outboard-launch and top-launch) excite toroidal refractive index (n_ϕ) spectra peaked around 5 with full width at half maxima of around 2. Wave excitation calculation using COMSOL Multiphysics shows that the excited power of the n_ϕ = 5 LHW component increases rapidly when the plasma cutoff density layer (where $n_e = 5 \times 10^{14}$ m^{-3}) becomes closer than 27 mm from the antenna surface, in agreement with experiment. Experimentally, the density profile in front of the antenna can be controlled by adjusting the side limiter location or antenna-plasma distance, and should be optimized for antenna-plasma coupling, since too high coupling results in a broadened and less directional n_ϕ spectrum, and too low coupling results in a less efficient power coupling, which necessitates recirculation of the transmitted power. Using these antennas, successful ST plasma start-up and I_p ramp-up to over 25 kA (about 1/4 of the nominal I_p for OH operation) have been achieved with RF power of less than 100 kW in about 40 ms.

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