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ACTIVE-PASSIVE WAVEGUIDE ARRAY FOR
WAVE EXCITATION IN PLASMAS

BY

R. W. MOTLEY AND W. M. HOOKE

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Wave Excitation in Plasmas

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Wave Excitation in Plasmas

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ABSTRACT

A modified version of the standard waveguide grill for exciting lower hybrid plasma waves is proposed. This version should reduce both the number of RF drive components and the amplitude of the (undesirable) surface waves. Results from a simple 2-element array are presented.

Phased waveguide arrays or "grills"^{1,2} appear to be ideal antennas for launching lower hybrid heating waves into overdense toroidal plasmas. All tests to date have demonstrated that the electromagnetic fields within the waveguides excite electrostatic plasma waves efficiently,³⁻⁶ provided conditions for accessibility⁷ and plasma loading are satisfied. In published experiments up to this time the individual elements of an even numbered array have been driven at approximately the same power level. This arrangement, although it generates a narrow wavenumber spectrum, is not ideal in other respects. Inevitably, equal power excitation is not an optimum configuration for minimizing surface waves;⁸⁻¹⁰ practically, it requires a costly, cumbersome manifold of coaxial lines to supply power to each of the guides.

In this paper we propose a modification of the classic grill configuration in which only alternate elements of the grill are excited. The passive elements, however, are not terminated; this arrangement would waste reflected power from the adjacent active elements and would also broaden the spectrum. Instead, we propose that the power reflected from the plasma into the idle guides be reflected back into the plasma column. If the phase of the reflected signal is adjusted such that the electric field at the throat of the idle guides is 180° out of phase with the fields of the adjacent guides, then the coupling and wavenumber spectrum would be similar to that of the evenly excited configuration.

To demonstrate the practicality of our proposal we have tested a 2-element, teflon-loaded waveguide in the B-1 test plasma,¹¹ which produces a magnetically confined (B=16 kG) plasma 2 m long and 10 cm in diam., with an argon plasma density $\sim 10^{12} \text{ cm}^{-3}$. The waveguide grill was placed at the surface of the plasma in the midplane. Only one of the elements was excited by low power ($\sim 10 \text{ W}$) pulses from a 2.45 GHz power source.⁷ Power coupled from the active guide into the passive guide was reflected back into the plasma by a short-circuited coaxial line of variable length.

The variation of the reflected power (in the active guide) as a function of the phase of the reflected signal in the adjacent guide is shown in Fig. 1. The reflectivity was found to vary from 2% (180° phasing) to 33% (0°), a pattern very similar to that obtained earlier with symmetric excitation,³ both in magnitude and phase. The circulating power in the idle guide was 20% of the input power (at 180°).

One can calculate the expected reflectivity of this new configuration from the linear Brambilla theory², simply by matching input and output in the "idle" guide and noting the reflection in other waveguide. The theoretical reflected power (Fig. 1) varies from 6% (at 180°) to 27%, i.e., over a somewhat smaller range than found in the experiment. The difference is not significant experimentally, since it can be accounted for by a reflection of only 10^{-3} of the input power from an imperfection in the waveguide or in the coax-to-waveguide adaptor. The circulating power should theoretically be 10% of the input power.

Minimum reflectivity usually implies preferential excitation of plasma resonance cones instead of surface waves. To check this aspect we measured the radial RF field structure with a triaxial probe placed 15 cm downstream from the waveguide. In Fig. 2 we see that the waves well within the plasma column are enhanced by 40-50% by reflecting the power in the passive guide at the proper phase. Thus the tuned waveguide elements not only minimize reflection, but also maximize the fractional power generated in the penetrating wave component, i.e., resonance cones.

The success of this simple 2-element waveguide on a test plasma suggests that an active-passive grill may be usefully employed as a multi-element wave exciter on tokamak plasmas. The character of this configuration leads naturally to an odd number of guide elements. In a 3-element, 800 MHz grill designed for the FRT tokamak we calculate that the total reflectivity should be 16% ($n = 10^{13} \text{ cm}^{-3}$), with the circulating power in the outer passive guides 3.5% and in the central guide 14% (compared with the power in each active guide). An attractive feature of this design is that the amplitude of the surface waves should be less than 2/3 that of a conventional grill.

Provided nonlinear effects do not change the phase of the reflected signal, one can introduce an additional simplification of the grill by eliminating the tuning sections outside the vacuum vessel and designing alternative elements of shorted reflecting waveguide inside the vessel. For each array

one then reduces the number of expensive custom ceramic windows by a factor of two.

The fact that all the active guide elements are driven in phase suggests one further practical development of this configuration: all of the power to the grill can be delivered in standard waveguide using a commercial ceramic vacuum window. Beyond the window the power can be diverted into alternate active waveguide elements; the passive elements can be fixed-tuned or tunable by adjustable shorting elements within the vacuum vessel. In principle one can suppress all of the reflection from this grill by using one tuner in the single waveguide section. A simple 5-element grill is illustrated in Fig. 3.

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Fig. 1. Reflected power in the passive waveguide as a function of the phase angle between the electric fields in the two waveguides. The total waveguide dimensions were 6×3.8 cm; $V_n \sim 10^{12} \text{ cm}^{-4}$; $B = 6$ kG.

Fig. 2. Radial variation of RF wave amplitude in a cross section 15 cm from the waveguide. The diameter of the plasma column was 10 cm.

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Fig. 3. A 5-element active-passive grill. The passive elements are $1/4$ wavelength long. Arrows indicate the direction of power flow.

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