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The Whistler Traveling Wave Parametric Amplifier (WTWPA)

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A whistler traveling wave parametric amplifier (WTWPA) model has been developed using second-order nonlinear plasma theory to explain the strong amplification observed during the NG-13 flight of Cygnus. A BT-4 rocket engine burn demonstrated that kinetic energy from a hypersonic neutral jet could be transferred to whistler waves in a space plasma. The WTWPA theory employs charge exchange of rocket exhaust injected perpendicular to the earth's magnetic field to drive lower-hybrid waves that act as an electrostatic pump for a plasma parametric amplifier. An external whistler wave is the input signal for the parametric amplifier and a second lower-hybrid wave is the idler signal that satisfies the necessary conditions for frequency and wave number matching. The nonlinear ponderomotive force from electron momentum and the nonlinear currents that drive the whistler wave equation provide second-order nonlinearities in the WTWPA. Spatial growth is established as the whistler propagates though an activated plasma medium, which has a negative conductivity at the matched signal wave frequency. Negative conductance has long been known for microwave parametric amplifiers, but not for plasma devices. The whistler wave and idler wave grows exponentially when passing through this medium until either the signal leaves the active region or the lower hybrid pump wave is depleted by transferring electrostatic energy to the idler and signal waves.

The WTWPA model provides a useful description of broadband whistler wave amplification that is powered by rocket exhaust plume injected across magnetic field lines. The broadband feature is a result of the broad spectrum of lower hybrid waves excited by the energetic ion ring distribution of gyrating pickup ions. This broadband nature implies that only a small fraction of the available LH wave energy is extracted to amplify a specific, narrowband whistler signal. The conversion of chemical energy into amplified electromagnetic energy has low efficiency based on both the WTWPA model and on measurements during the Cygnus NG-13 experiment. There is, however, an abundance of kinetic energy from the chemical reactions producing rocket plume and both experiment and models demonstrate that the gain of the WTWPA can easily be greater than 30 dB for a typical exhaust cloud from a small, 150 g/s, hydrazine rocket engine. The pump fields are oblique lower hybrid waves, which are established with maximum amplitude based on saturation of the LH instability. The amplitudes and frequency spectrum of pump and the impact of pump depletion needs to be estimated with an electrostatic (PIC) simulation. Future experiments with dedicated Cygnus burns in space and a large plasma column aligned with a cylindrical magnetic field in the laboratory environment. These will be designed to test the presence of the three-waves involved in the parametric amplification process.

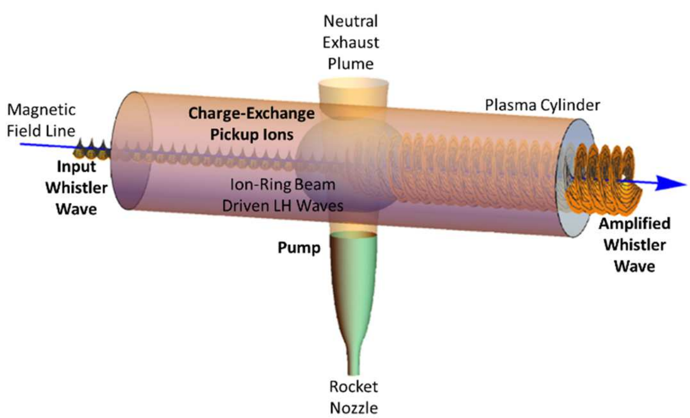

Fig. 1. Prototype design of the REDA physical device. The amplitude of the right hand circular polarization is represented as a spiral with growth after passing though the activated region with the ion-ring beam distribution

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