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Analysis of the Backscatter Spectrum in an Ionospheric Modification Experiment

by

Hongjin Kim

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CASE FILE

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SUIPR Report No. 509

Sponsored by
NASA Grant NGL 05-020-176
and
Defense Advanced Research Projects Agency
ARPA Order No. 1733

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through the Office of Naval Research
(Contract No. N00014-67-A-0112-0066)

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ANALYSIS OF THE BACK SCATTER SPECTRUM
IN AN IONOSPHERIC MODIFICATION EXPERIMENT

by

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ABSTRACT

The purpose of this study is to compare predictions of the back-scatter spectrum, including effects of ionospheric inhomogeneity, with experimental observations of incoherent backscatter from an artificially heated region. Our calculations show that the strongest backscatter echo received is not, in fact, from the reflection level, but from a region some distance below (about 0.5 km for an experiment carried out at Arecibo), where the pump wave from a HF transmitter (~100 kW) is below the threshold for parametric amplification. By taking the standing wave pattern of the pump into account properly, the present theory explains the asymmetry of the up-shifted and down-shifted plasma lines in the backscatter spectrum, and the several peaks typically observed in the region of the spectrum near the HF transmitter frequency.

INTRODUCTION

From experimental results obtained at Arecibo (Carlson, Gordon and Showen, 1972; Kantor, 1972), it is believed that the enhanced heating and anomalous absorption occurring in the ionosphere are mainly due to parametric decay instabilities; the HF ordinary (pump) wave propagating in the F-layer from a high power transmitter (~100 kW) decays into electron plasma and ion acoustic waves to enhance the plasma fluctuations (DuBois and Goldman, 1965; Nishikawa, 1968). Several analyses have been carried out of the saturation spectra in homogeneous (DuBois and Goldman, 1972a and b%3B Valeo, Oberman and Perkins, 1972; Kruer and Valeo, 1972; Harker, 1972; Kuo and Fejer, 1972; Fejer and Kuo, 1972; Perkins and Valeo, 1973) or inhomogeneous (Arnush, Fried and Kennel, 1972a and b) plasmas, with the assumption that the pump field is well above the threshold for parametric amplification. This results in saturation of the electron plasma waves due to their nonlinear Landau damping by positive ions, or due to their absorption by electrons whose orbits are nonlinearly perturbed by the waves (Bezzerides and Weinstock, 1972). However, some essential features of the backscatter spectrum still remain to be explained. For example, Carlson et al. (1972) have obtained a pair of plasma lines in the spectrum enhanced by the pump wave

(f
0
= 5.62 MHz). These plasma lines are shifted up and down from the incoherent scatter diagnostic beam (fi = 430 MHz) by f -f where
f
a
O 'a'
and
4 kHz) is the frequency of the ion acoustic waves generated, differ from each other in the intensities of the peaks. As shown in Fig. 1, Kantor (1972) has also observed several maxima and minima near the peaks of the spectrum. So far, these features of the spectrum have not been explained.

The purpose of the present analysis is to take the inhomogeneity of the ionosphere into account and to compare our predictions with observations of incoherent scatter. In contrast to most of the previous analyses, our theory assumes that the pump is below the threshold. Section II is concerned with the pump wave. Its intensity is derived as a function of height. In Section III, the intensity of the parametrically enhanced

TEMPERATURE (10^3 °K)
60-
50■
40
30
1
090225 TO 090253 AST
16 DEC 71
$\sigma = 4.7\%$
0.98 kHz RESOLUTION
foF■ 8.2 MHz
DOWNSHIFTED
UPSHIFTED
20-
SNR = 132
SNR = 37
10-
O
5 10 15 20 ΚΗΣ
20
15 10 5
DISPLACEMENT FROM
(fi-fa)
DISPLACEMENT FROM
(fi + fa)

FIG. 1. Frequency spectrum obtained by incoherent backscatter at Arecibo (Kantor, 1972).

electron plasma wave is obtained from the kinetic wave equation. Section IV is devoted to the incoherent scatter experiment performed at Arecibo, and frequency spectra are obtained for several cases. Our assumptions are discussed and predictions are compared to experimental data in Section V.

.

II. INTENSITY OF THE PUMP WAVE

As the pump wave from the HF transmitter propagates vertically upward in the ionosphere, its group velocity decreases very sharply near, and reaches zero at, the reflection level, as shown in Fig. 2. Since more slowly moving waves spend a longer time in a location, and are thus able to exchange energies more effectively, we shall assume that energy from the pump wave is deposited in the ionosphere only at or very near its reflection level and we neglect the depletion of its intensity due to the linear or nonlinear loss in the region of interest. The present investigation is primarily concerned with heating at frequencies below the penetration frequency, so that the electron density profile can be approximated by a linear profile, as shown in Fig. 2(a). For simplicity, we neglect the geomagnetic field.

After the pump

field is found, however, it is regarded as being aligned in the direction of the geomagnetic field.

A vertically propagating ordinary wave, of angular frequency is described by the wave equations

d²E
4. (2)².
dz
+
W
€(z) E = 0,
for z ≥ 0 (in the ionosphere)
(1)
d² E
+
dz
37. (2000)²,
E = O
for z < 0 (in the free space),
where ■
is the height measured from the base of the ionosphere (z
and is normalized to the scale height ho;
=
0),
■ is the speed of light;B
the wave magnetic field is related to the electric field by
1
B =
iw ho
dE
dz
,
and the plasma equivalent permittivity, € (z)
€(z) = 1
-
4
= 1
is given by
,
Z
(2)
(3)