X-615-68-185

PREPRINT

NASA TM X-63216

SATELLITE OBSERVATIONS OF RADIO NOISE IN THE MAGNETOSPHERE

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MAY 1968

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by

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Noise bands at medium frequencies appear to originate from energetic particle interactions with the thermal plasma. Their cutoffs are determined by magneto-ionic parameters of the medium and can be used to determine local plasma density.

Observations on sounding rockets[1-3] and satellites[4,5] have shown evidence for enhanced noise bands in the ionosphere and magnetosphere, especially between the plasma frequency f_N and the upper hybrid frequency $f_T = (f_N^2 + f_H^2)^{\frac{1}{2}}$, where f_H is the electron gyrofrequency.

Our recent observations on the ATS II satellite have provided new information on these noise bands to altitudes of about 8000 km. The Radio Astronomy Experiment on ATS II consisted of a Ryle-Vonberg radiometer operating at seven discrete frequencies between 450 kHz and 3 MHz. The antenna system was composed of a dipole antenna 76 meters from tip to tip. The orbit of the ATS II satellite, launched in April 1967, ranged from an initial perigee of $\sim$180 km to an apogee of $\sim$10,000 km, with an orbital inclination of $\sim 30^{\circ}$.

In this altitude range various magneto-ionic conditions are encountered for the seven fixed observing frequencies, four of which (450 and 700 kHz; 1.6 and 2.2 MHz) were used for the noise observations. Figure 1 shows the trajectories in the X-Y^2 plane (or CMA diagram) for the frequencies 450 kHz, 700 kHz and 2.2 MHz using a model distribution of electron density and geomagnetic field.

Typical examples of observed noise enhancements are shown in Figure 2. A composite picture of noise bands at 700 kHz appears in Figure 2a and typical noise bands at 2.2 MHz in Figure 2b, where relative intensity is given as a function of altitude. In addition to the pronounced noise band between plasma frequency $f_N (X = 1)$ and upper hybrid frequency $f_T (X=1-Y^2)$, other noise enhancements corresponding to various magneto-ionic regimes can be recognized in the data. The noise enhancements are generally about 10 to 20 db above the background; their absolute intensity is estimated to be $\sim 10^{-19}$ to $10^{-18} W/m^2/Hz/sterad$.

The nature and origin of these noise bands, is as yet not understood. Generation by energetic particles, as well as antenna impedance effects have been suggested as possible explanations. The latter, however, is not inconsistent with the former explanation, since the observed increased resistive component of the driving point impedance could be a consequence of losses due to plasma wave generation.

A possible source for the magnetospheric radio noise is the generation of plasma waves by energetic particles, e.g. by the Cerenkov process[6,7]. Necessary conditions for plasma wave generation are, that the velocity of the exciting particles is greater than the thermal velocity of the plasma and greater than the phase velocity of the waves in the plasma. Since the particle velocity must be less than the velocity of light, this condition also corresponds to a large refractive index, i.e. $n >> 1$. Because of the electrostatic nature of plasma waves, they will normally not be detected with an electromagnetic antenna, located at a distance from the source. However, direct coupling of plasma waves to e.m. waves is possible for those modes whose phase velocities are nearly equal[8]. In addition, plasma waves can be converted into e.m. waves via density gradients or inhomogeneities[9,10]. In Figure 3 we show in a schematic manner on the CMA diagram the regimes where plasma wave generation can occur and where coupling of these waves to the slow e.m. mode is possible. It can be seen that this is the case in region I and III, i.e. corresponding to the principal noise band between plasma and upper hybrid frequency and to the noise band at low frequencies ($f < f_N$, f_H), which also includes the well known VLF noise emissions. In region II, plasma wave generation is not possible; however, e.m. waves arising from plasma waves generated in region I (generally at higher altitudes) can propagate in one mode (across the magnetic field) into the region of higher density where the noise is observed.

We observe quite regularly noise bands in regions I and III and on a somewhat intermittent basis in region II. Corresponding to the latter, we have also observed noise at 700 kHz at altitudes as low as 300 km in the vicinity of the South Atlantic anomaly (L = 1.35), the L shell where intense noise bands have also been observed on the ARIEL II satellite[11].

Although the details of the noise enhancements are not fully understood, it is highly suggestive that their origin is due to the interaction of energetic particles with the ambient plasma. In any event, the conditions for generation of plasma waves and coupling into e.m. waves are met in the regions where the principal magnetospheric noise enhancements are observed. Further investigations are underway to study the details of the observed noise bands and their relation to other magnetospheric phenomena.

The principal noise band between f_N and f_T which shows relatively sharp cutoffs can also be used to determine local plasma density; other magneto-ionic cutoffs can sometimes also be uniquely identified. From these cutoffs we have determined local plasma density by utilizing gyrofrequencies, f_H, from a geomagnetic field model based on a 64 coefficient spherical harmonic expansion. Figure 4 shows the electron density distribution as a function of altitude derived from the noise measurements at four frequencies. The plasma density values corresponding to data for April/May 1967 over a latitude range $\pm 30^{o}$ agree well, at lower altitudes, with representative data from the Alouette II satellite; in the altitude range from 1.5 to $2R_e$ the densities derived by us are in good agreement with other satellite observations[12].

It thus appears that radio noise observations in the magnetosphere may be an important method not only for the study of wave-particle interaction phenomena but also for the determination of local plasma density.

This note will appear in NATURE, 1968.

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FIGURE CAPTIONS

Figure 1

Trajectories in the $X-Y^2$ plane (CMA diagram) of three observing frequencies, indicating magneto-ionic conditions expected along the satellite orbit, for an assumed model distribution of plasma and gyrofrequency.

Figure 2

Typical noise enhancements observed at a) 600 kHz and b) 2.2 MHz. The relative amplitude of noise enhancements is shown as a function of altitude. Also indicated are approximate magneto-ionic conditions delineating various noise bands.

Figure 3

Schematic CMA diagram showing regions where plasma wave generation and coupling to (or propagation of) e.m. waves is possible. Regions I, II and III correspond to domains where noise enhancements are observed on the ATS II satellite.

Figure 4

Electron density distribution as a function of altitude derived from cutoffs of magnetospheric noise enhancements. A representative Alouette II profile is also indicated.

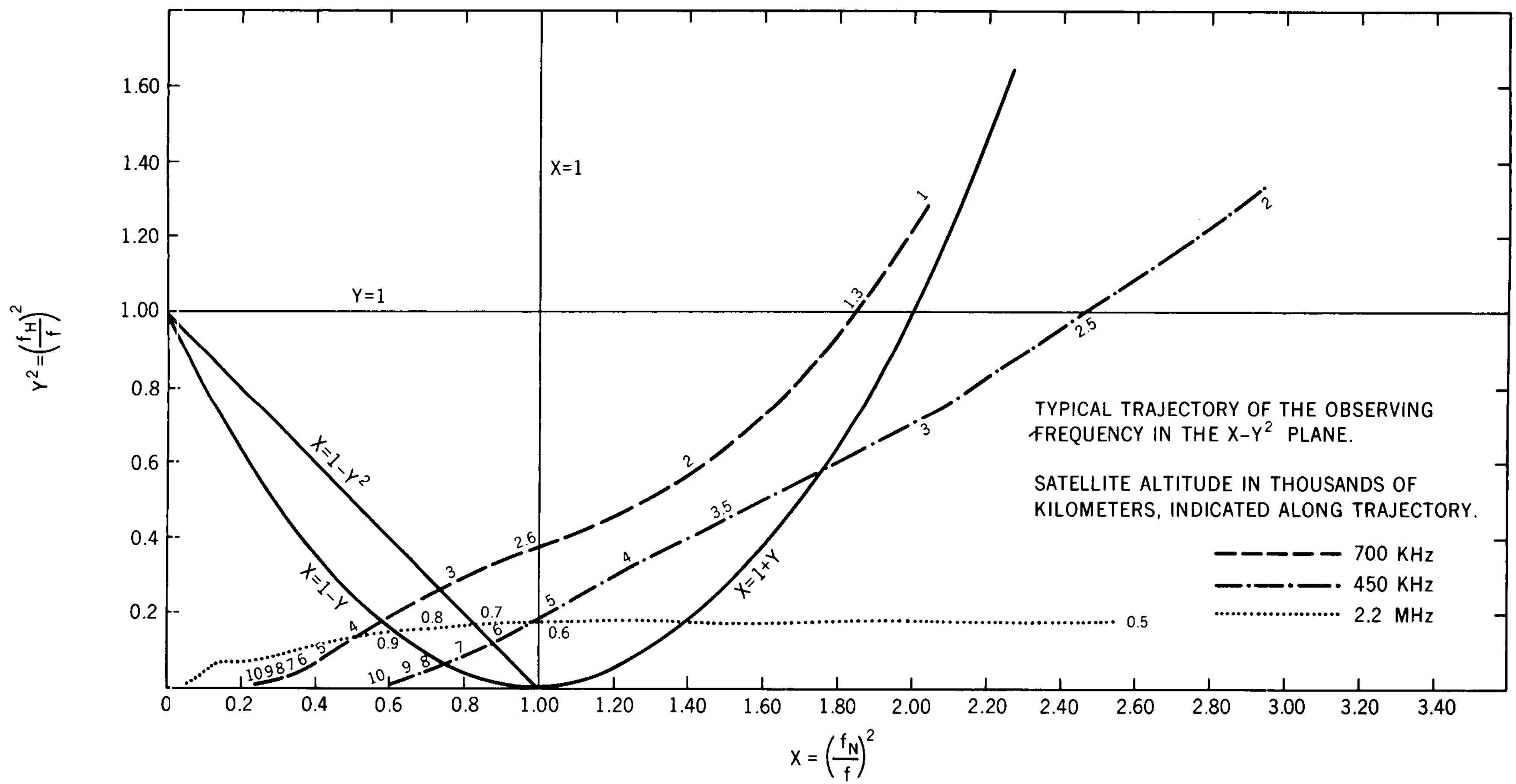
TYPICAL TRAJECTORY OF THE OBSERVING FREQUENCY IN THE X-Y² PLANE.
SATELLITE ALTITUDE IN THOUSANDS OF KILOMETERS, INDICATED ALONG TRAJECTORY.
700 KHz
450 KHz
2.2 MHz
X=1
Y=1
X=1-Y²
X=1-Y
X=1+Y
Y² = (f_H/f)²
X = (f_N/f)²

Figure 1.

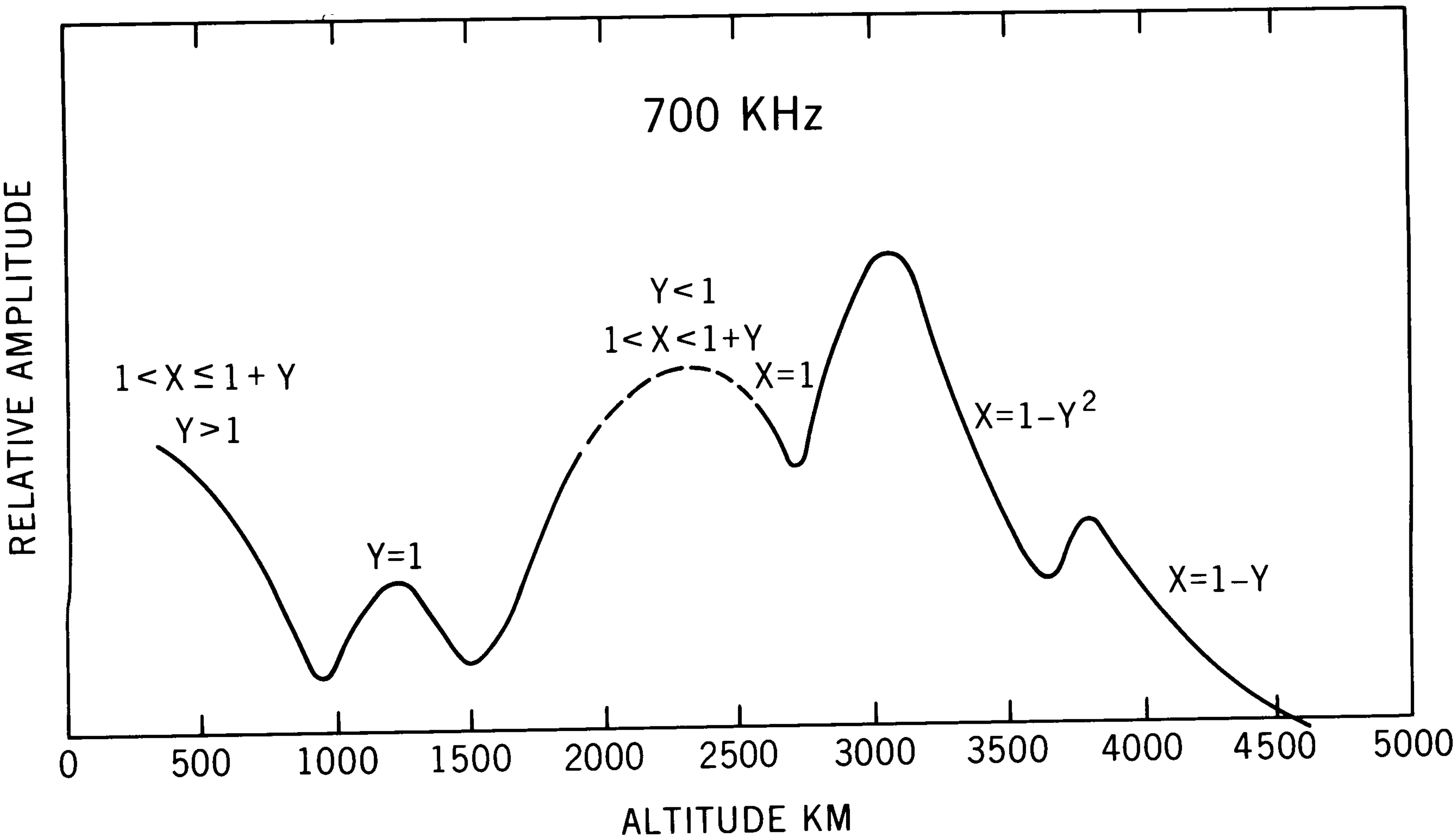
700 KHz
RELATIVE AMPLITUDE
1 < X ≤ 1 + Y
Y > 1
Y=1
Y < 1
1 < X < 1 + Y
X=1
X=1−Y²
X=1−Y
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
ALTITUDE KM

Figure 2a.

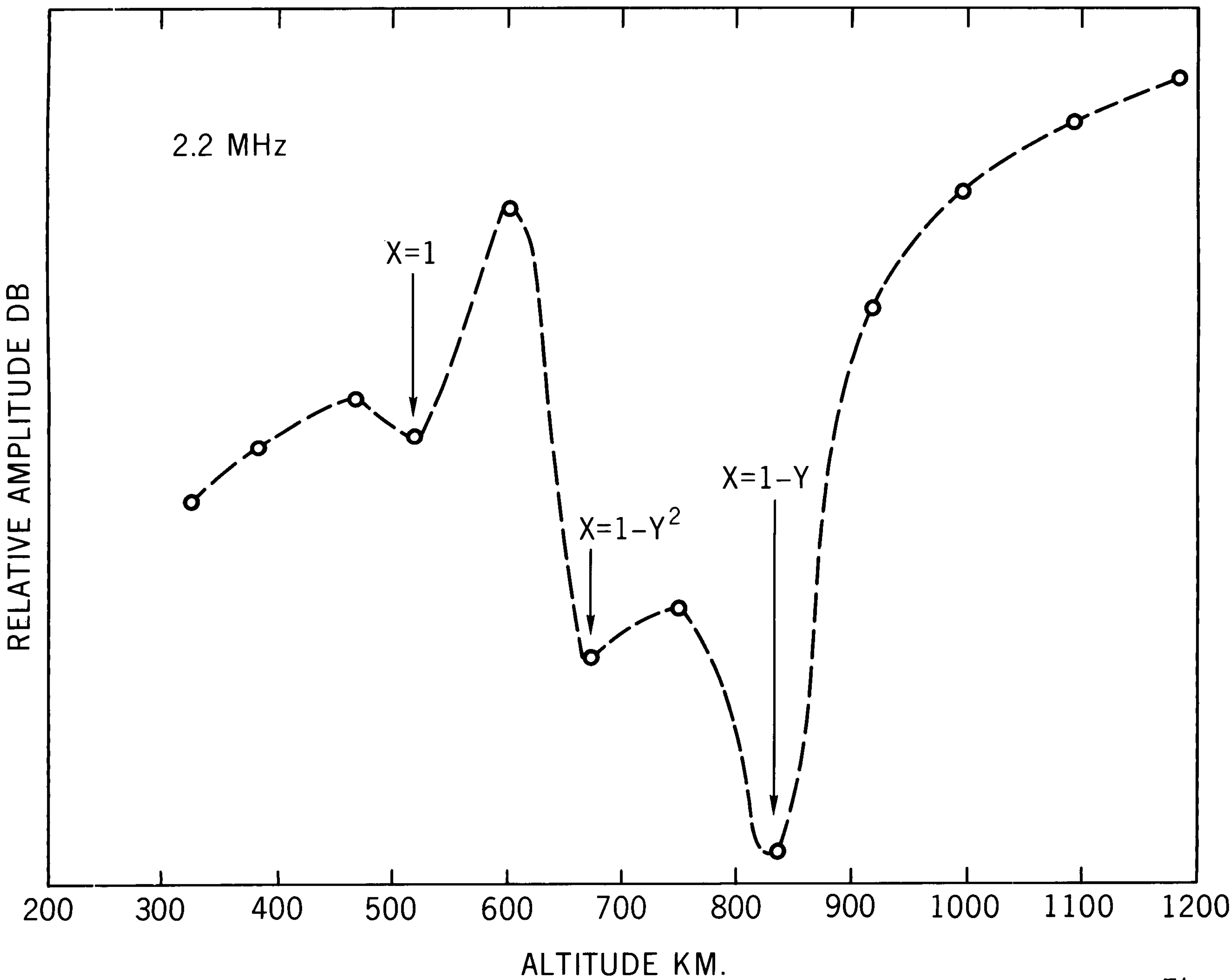
2.2 MHz
X=1
X=1-Y^2
X=1-Y
RELATIVE AMPLITUDE DB
200
300
400
500
600
700
800
900
1000
1100
1200
ALTITUDE KM.

Figure 2b.

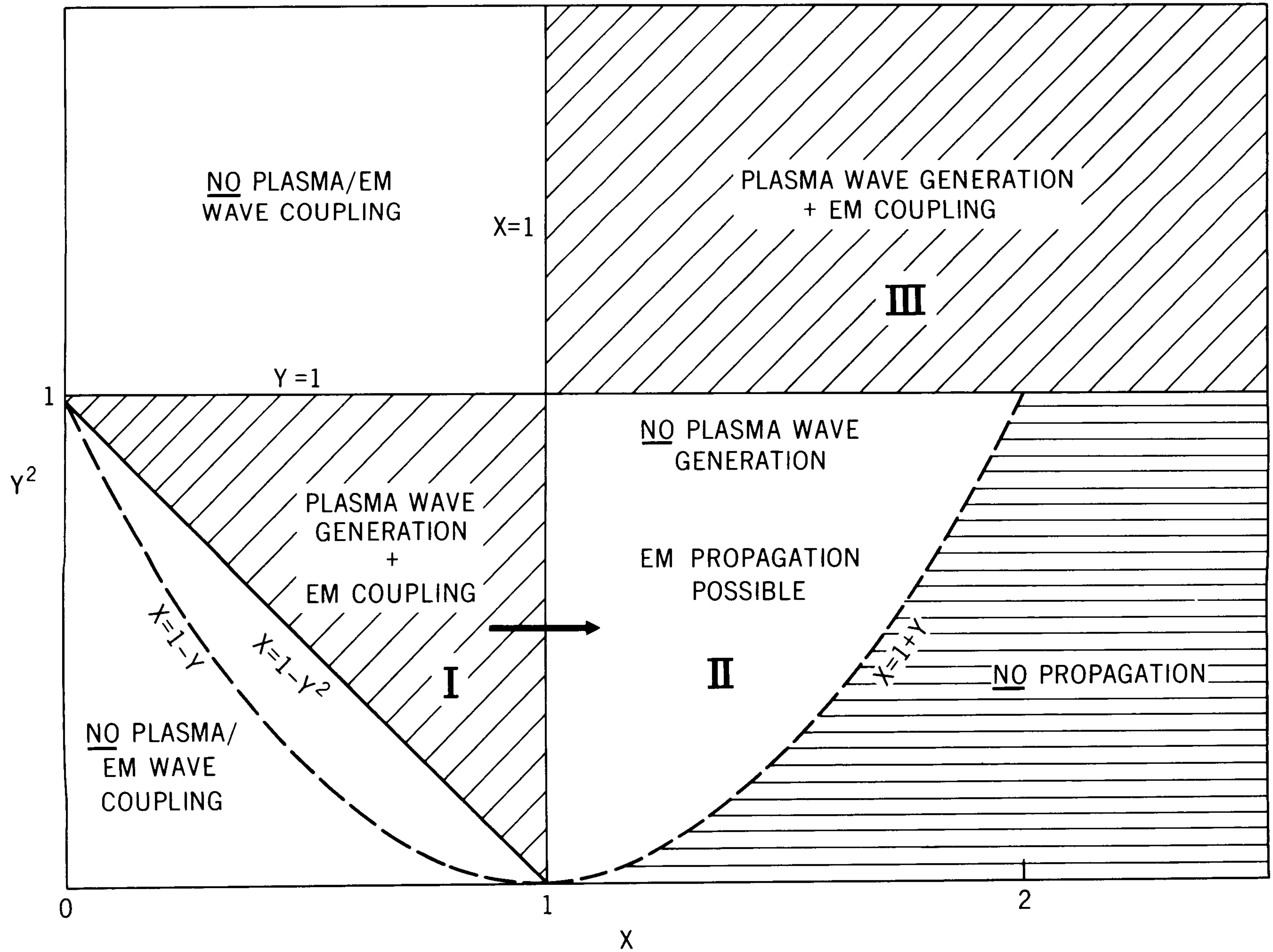
NO PLASMA/EM
WAVE COUPLING
X=1
PLASMA WAVE GENERATION
+ EM COUPLING
III
Y =1
1
Y^2
NO PLASMA WAVE
GENERATION
PLASMA WAVE
GENERATION
+
EM COUPLING
EM PROPAGATION
POSSIBLE
X=1-Y
X=1-Y^2
I
II
X=1+Y
NO PROPAGATION
NO PLASMA/
EM WAVE
COUPLING
0
1
2
X

Figure 3.

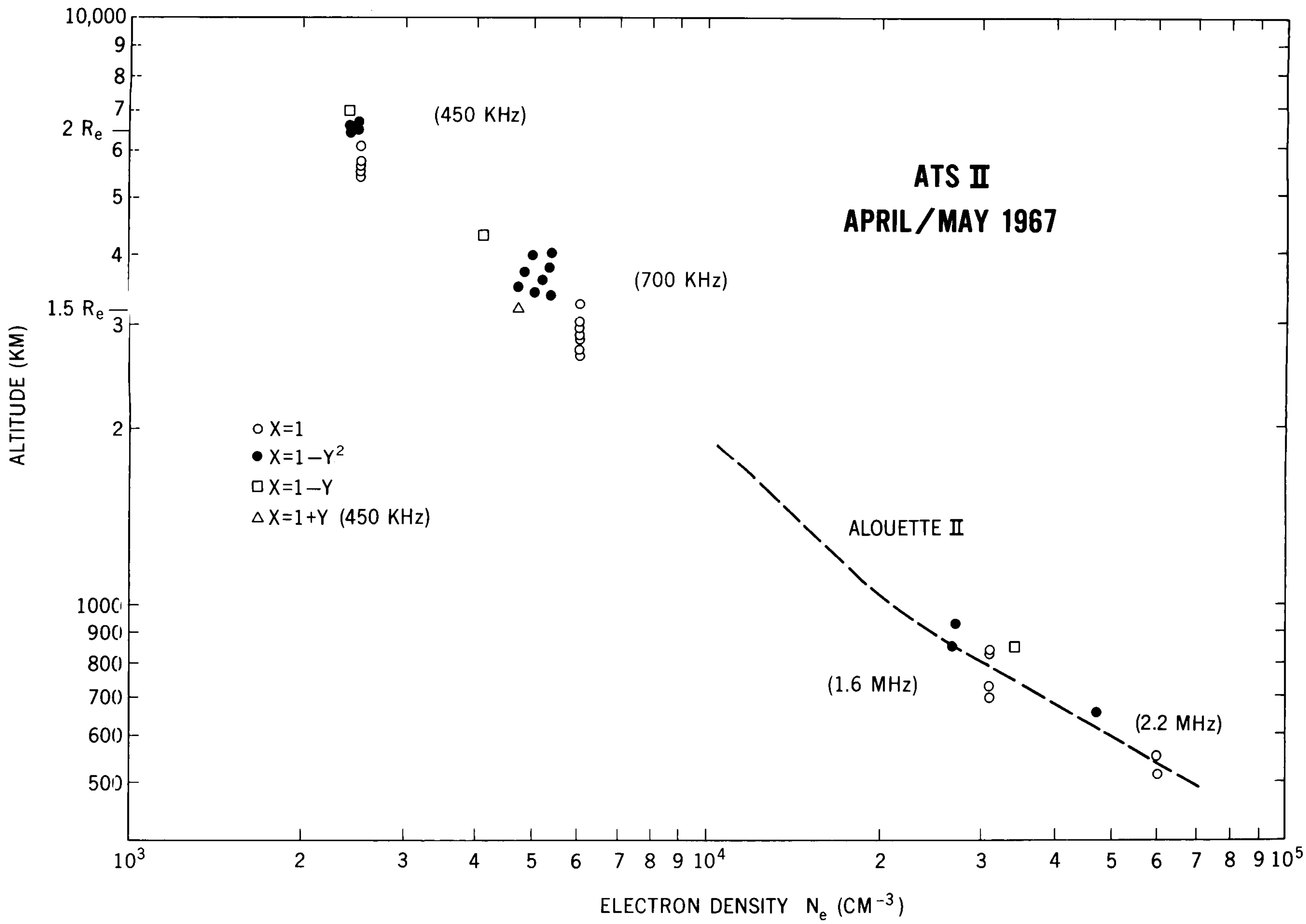
ATS II
APRIL/MAY 1967
(450 KHz)
(700 KHz)
ALOUETTE II
(1.6 MHz)
(2.2 MHz)
○ X=1
● X=1−Y²
□ X=1−Y
△ X=1+Y (450 KHz)
ALTITUDE (KM)
2 Re
1.5 Re
ELECTRON DENSITY Ne (CM⁻³)

Figure 4