

RADIATION RESISTANCE OF A LOOP ANTENNA IN TWO-COMPONENT WARM PLASMA

R. K. GUPTA AND ANIL KUMAR

Malaviya Regional Engineering College, Jaipur 302 017, India.

ABSTRACT

The variation of experimentally measured values of radiation resistance of a loop antenna on Ariel-3 satellite with plasma frequency is explained by developing a theory of square loop antenna in two-component warm plasma. It is observed that the theoretically computed values of radiation resistance are now more closer than the values calculated using earlier theories.

INTRODUCTION

A THEORY of radiation from rectangular loop aerial immersed in single-component warm plasma was earlier developed¹ and the variation of radiation resistance with plasma frequency computed from this theory was compared with the corresponding measured values recorded² for a loop antenna fixed on board Ariel-3 satellite. It was observed³ that theoretical results obtained using one-component plasma theory differ by a factor of 10^{-2} from experimental values. In order to make the theory more comprehensive, the effect of ions has also been taken into account and expressions have now been developed for the electromagnetic and the plasma components of radiation resistance of loop antenna in two-component (electron-ion) warm plasma. The theoretically computed values, thus obtained are compared with the observed values by Ariel-3 satellite. It is noticed that the agreement between theory and experiment is now closer. The values computed using one-component electron theory are also plotted for comparison.

THEORETICAL EXPRESSIONS FOR RADIATION RESISTANCE

The amplitude of the current along each radiator of the square loop shown in figure 1a, is assumed to vary sinusoidally with position, with the peak of the current occurring at the centre of each radiator. Mathematically

$$I(z) = I_m \cos [\beta(l/2 - z)] \quad (1)$$

where I_m is the current at the centre of each conductor, β is the propagation constant of the current on the wire and z is the distance along the aerial. Using linearized hydrodynamic theory and following the usual methods¹, the following expressions for the electromagnetic and the plasma components of the radiation resistance of the square loop in the two-component warm plasma have been derived.

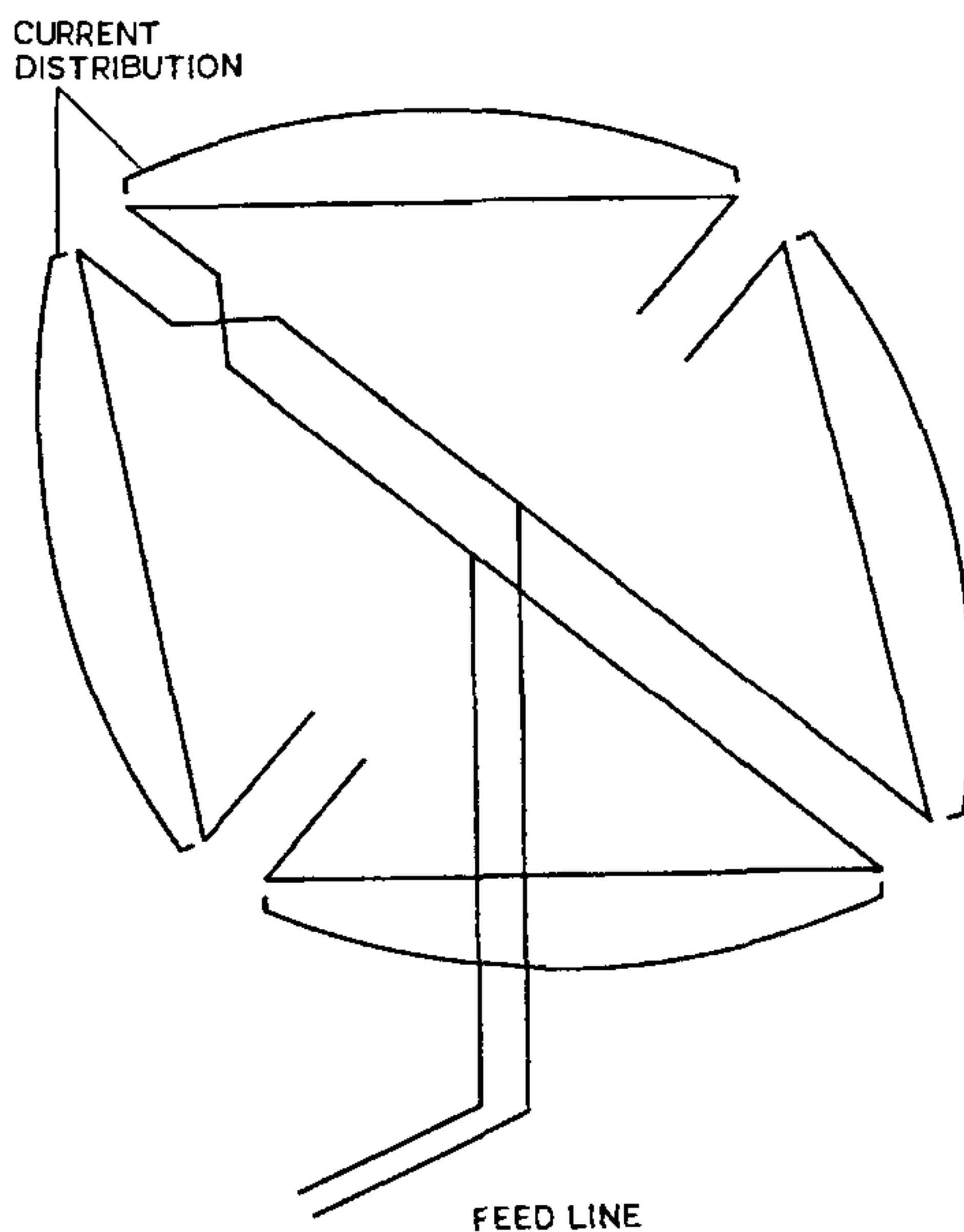


Figure 1a. Current distribution on the loop antenna.

$$R_e = \frac{30}{\pi} \frac{a^2}{A} \int_0^\pi \int_0^{2\pi} \left[x^2 \alpha_1^2 \sin^2 \left(\frac{\beta l u_2}{2} \right) + y^2 \alpha_2^2 \sin^2 \left(\frac{\beta l u_1}{2} \right) + xy \sin^2 \theta \sin 2\phi \right. \\ \left. \sin \left(\frac{\beta l u_1}{2} \right) \sin \left(\frac{\beta l u_2}{2} \right) \right] X \sin \theta d\theta d\phi \quad (2)$$

$$R_{pj} = \frac{\omega_{pe}^2 (1 - \alpha_j)^2}{\omega 4 \pi^2 u_e^2 \epsilon_0 \beta_{pj} (1 + \alpha_j^2)} \int_0^\pi \int_0^{2\pi} x_j \cos$$

$$\left[\left(\frac{\beta_{pj} l}{2} \cos \theta_2 \right) + y_j \cos \left(\frac{\beta_{pj} l}{2} \cos \theta_1 \right) \right]^2 \times \sin \theta \, d\theta \, d\phi \quad (3)$$

where θ and ϕ are the azimuth and zenith angles of the spherical polar coordinate system, centred on the aerial (figure 1b) and

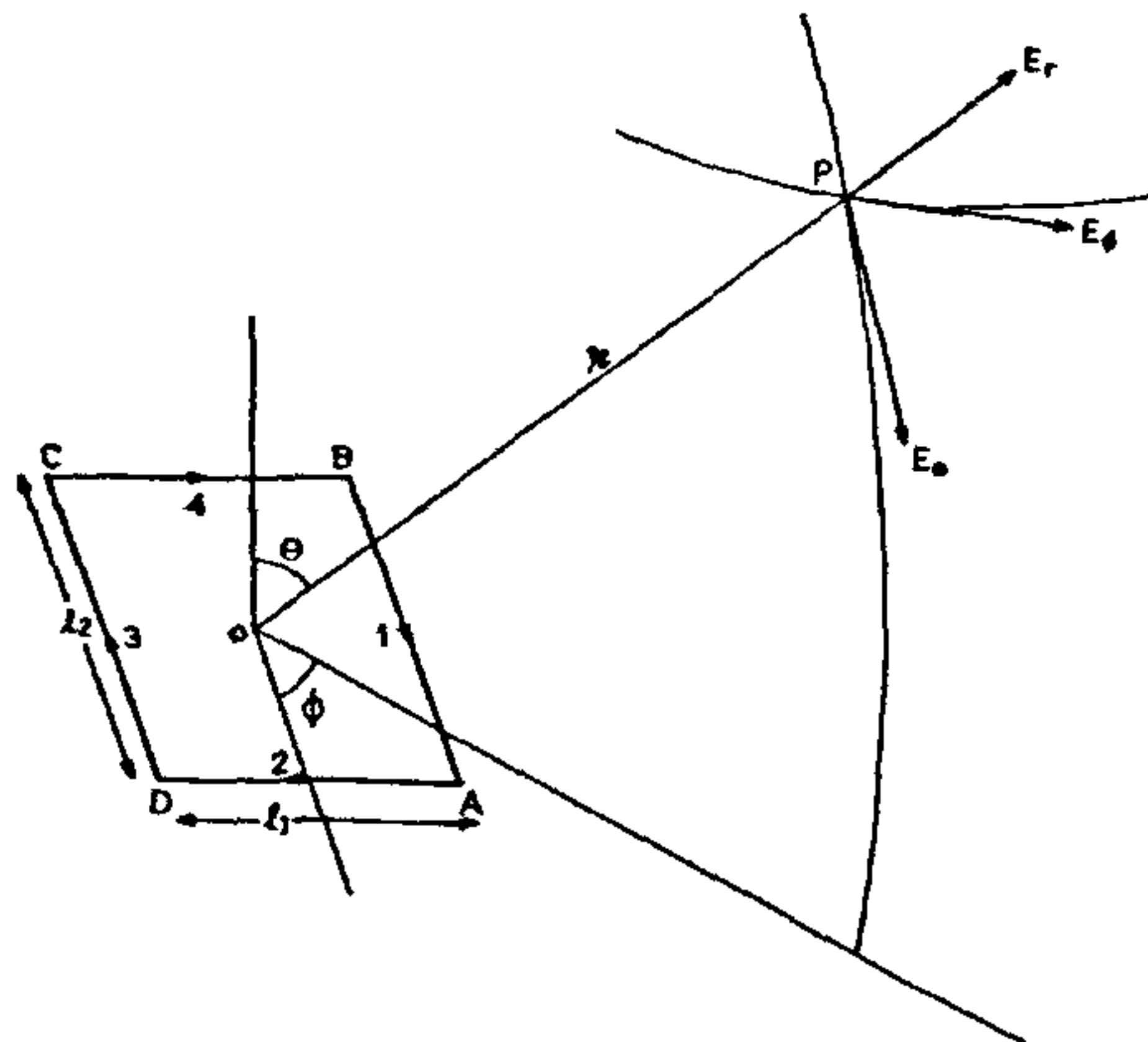


Figure 1b. Geometry of the loop antenna.

$$A = \left[1 - \left(\frac{\omega_{pe}^2}{\omega^2} + \frac{\omega_{pi}^2}{\omega^2} \right) \right]^{\frac{1}{2}}$$

$$\cos \theta_1 = \sin \theta \cos \phi, \cos \theta_2 = -\sin \theta \sin \phi \quad (4)$$

where θ_1 is angle between an AP and the radiator 1 and θ_2 is the angle between OP and radiator 2,

$$a = \frac{\beta_e}{\beta} \text{ where } \beta_e = \frac{\omega}{c} A$$

$$\alpha_1^2 = 1 - \cos^2 \theta_1, \alpha_2^2 = 1 - \cos^2 \theta_2$$

$$u_1 = a \cos \theta_1, u_2 = a \cos \theta_2$$

$$x = [\delta_1 \sin(\beta l \delta_2) + \delta_2 \sin(\beta l \delta_1)] / 2 \delta_1 \delta_2$$

$$y = [\delta_3 \sin(\beta l \delta_4) + \delta_4 \sin(\beta l \delta_3)] / 2 \delta_3 \delta_4 \quad (5)$$

where

$$\delta_1 = \frac{1-u_1}{2}, \delta_2 = \frac{1+u_1}{2}, \delta_3 = \frac{1-u_2}{2},$$

$$\delta_4 = \frac{1+u_2}{2}$$

and

$$x_j = \left(\frac{\sin \frac{\beta l}{2} (1-b_j \cos \theta_1)}{(1-b_j \cos \theta_1)} - \frac{\sin \frac{\beta l}{2} (1+b_j \cos \theta_1)}{(1+b_j \cos \theta_1)} \right)$$

$$y_j = \left(\frac{\sin \frac{\beta l}{2} (1-b_j \cos \theta_2)}{(1-b_j \cos \theta_2)} - \frac{\sin \frac{\beta l}{2} (1+b_j \cos \theta_2)}{(1+b_j \cos \theta_2)} \right) \quad (6)$$

$$\text{where } b_j = \beta_{pj} / \beta \quad j = 1, 2$$

β_{pj} are given by the roots of the quadratic equation

$$\beta_{pj}^4 - (T_{11} + T_{22}) \beta_{pj}^2 + (T_{11} T_{22} - T_{12} T_{21}) = 0$$

$$\text{where } T_{11} = \frac{\omega^2}{u_e^2} \left(1 - \frac{\omega_{pe}^2}{\omega^2} \right),$$

$$T_{12} = \frac{\omega_{pi}^2}{u_i^2} \quad T_{21} = \frac{\omega_{pe}^2}{u_e^2},$$

$$T_{22} = \frac{\omega^2}{u_i^2} \left(1 - \frac{\omega_{pi}^2}{\omega^2} \right) \quad (7)$$

and α_j is related as

$$\beta_{pj}^2 = T_{11} + T_{21} \alpha_j. \quad (8)$$

The total radiation resistance R_T is given by

$$R_T = R_e + R_{pj} \quad (j = 1, 2) \quad (9)$$

In the above expressions for radiation resistance, the value of β , the propagation constant of current distribution on the loop wire, is general. However, in our computation, we assume $\beta = \beta_e$ and evaluate R_e and

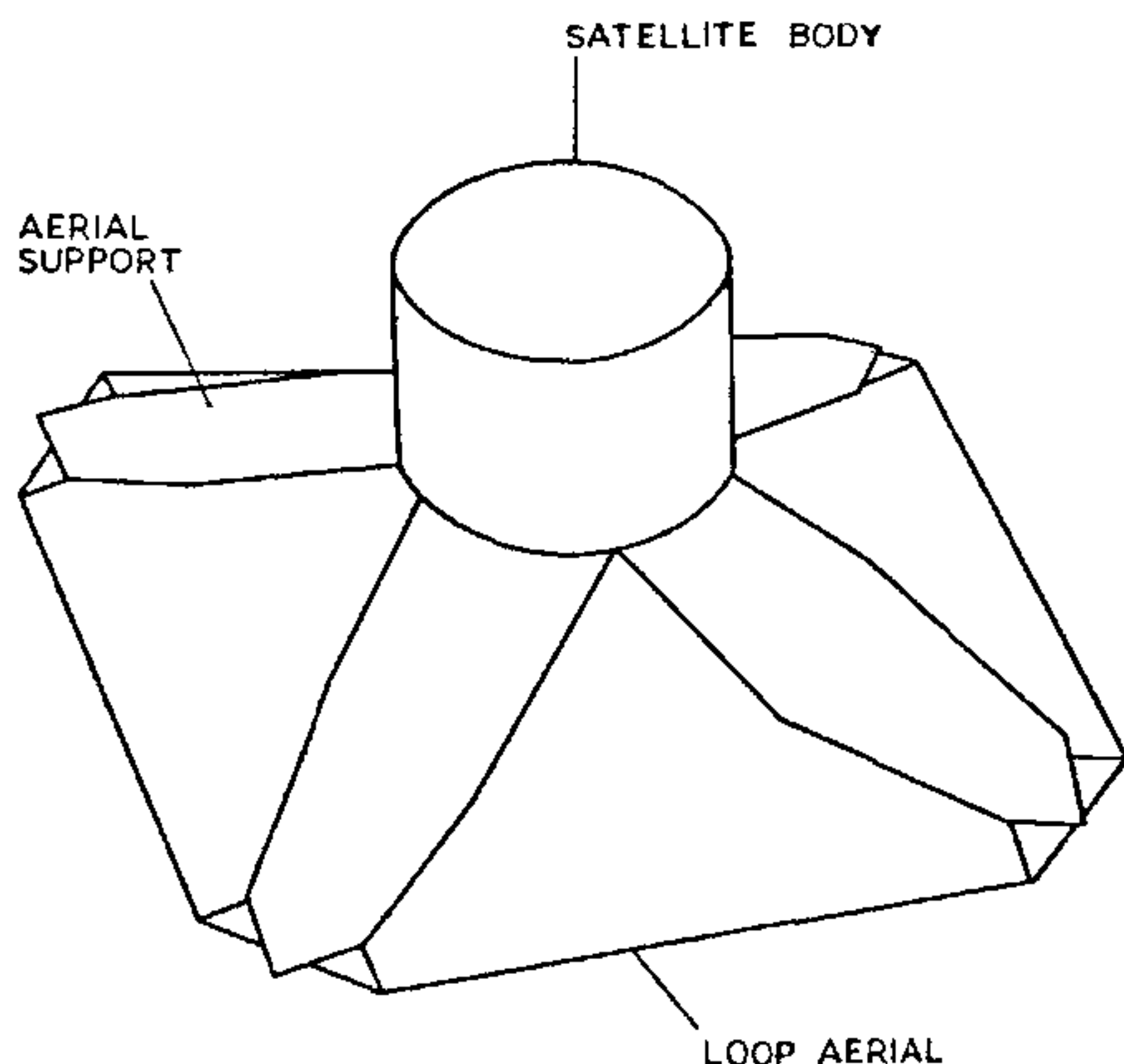


Figure 2. Ariel-3 satellite showing Jodrell Bank aerial.

R_{pj} by numerical computation.

The square loop aerial used on the Ariel-3 satellite (figure 2) has an effective area of 3.93 m^2 which corresponds to $k_0 = l/\lambda_0 = 0.0229$ at the operating frequency of 3.48 MHz. Substituting the above and taking $c/u_e = 10^3$ values of R_e and R_{pj} are calculated by numerical computation on APPLE computer using basic language.

The experimental values⁴ of R_T for the loop used in Ariel-3 satellite and the theoretical values of R_T calculated in single-component electron plasma and in the two component warm plasma are shown in figure 3. The bar shows the variation of experimental values during flight of the satellite.

DISCUSSION AND CONCLUSIONS

Some interesting observations can be made from figure 3. While the trend in variation of R_T with plasma frequency in the one and the two-component warm plasma remains almost the same. The values of R_T in the two-component plasma are higher as com-

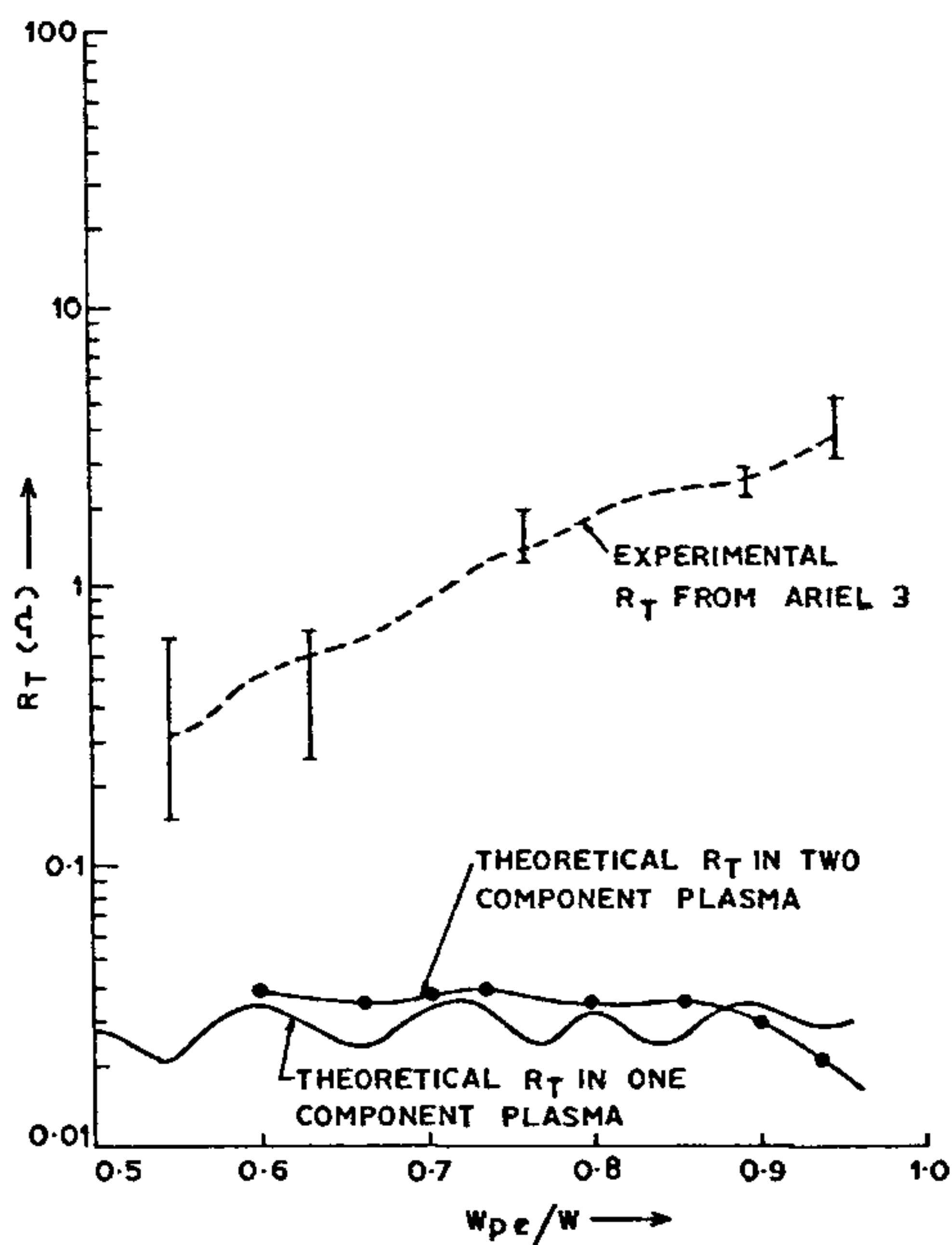


Figure 3. Comparison of theory with measurements for Ariel-3 at frequency of 3.48 MHz.

pared to the one-component warm plasma. The values are now closer to the experimentally observed values⁴. Although we have neglected the effect of earth's magnetic field and the formation of sheath effects, the theory developed here can provide meaningful results for a loop antenna in the plasma. It also shows that the effect of ions should be considered to obtain more accurate results. Further, the propagation constant for the current distribution can be assumed to be equal to β_e , the propagation constant of electromagnetic wave in plasma. Also, the theory developed here using linearized hydrodynamic theory for two-component warm plasma is capable of giving better results. However, this theory can only be applied for cases when the plasma frequency is less than the source frequency.

1. Freeston, I. L. and Gupta, R. K., *Proc. Instn. Elect. Engrs.*, 1971, 118, 633.
2. Freeston, I. L., Gupta, R. K. and Gregory, P. C., *IEEE-AP Symposium Digest*, 1969, 343.
3. Gupta, R. K. and Freeston, I. L., *Electron. Lett.*, 1971, 7, 199.
4. Gregory, P. C., *Planet Space Sci.*, 1970, 18, 1357.