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Theoretical and Experimental Investigations of Antennas and Waves in Plasma

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Parametric Interactions in a Dielectric Medium Space-Time Modulated by Two Pump Waves - B. Rama Rao.

During the last few years several authors[1,2] have considered the propagation characteristics of electromagnetic waves traveling in media with properties varying periodically in time and space. In all of these cases, it is tacitly assumed that the perturbing wave modulating the medium is a weak, progressive, sinusoidal disturbance. However, there are many applications in ultrasonics, quantum electronics, and in plasma and ionospheric physics where the modulating pump wave has a large amplitude and contains several harmonics of the fundamental pumping frequency. Alternatively, the dielectric medium can be subjected to "parallel pumping" by two pump waves of incommensurate frequencies. Electromagnetic wave propagation in dielectric media of this type has been analyzed. To keep the analysis simple, only the first two harmonics of the pump wave have been considered.

It is assumed that the high intensity pump wave (either acoustic or microwave phonon wave) traveling along the z direction in an infinite dielectric medium contains two pump harmonics and causes the dielectric constant of the medium to vary in the following manner

$$\varepsilon(z,t) = \varepsilon_0 + \varepsilon_1 \cos(\omega_v t - k_v z) + \varepsilon_2 \cos(2\omega_v t - 2k_v z)$$

where $\varepsilon_2 << \varepsilon_1 << \varepsilon_0$. ω_v and k_v are, respectively, the angular frequency and the wave number of the fundamental component of the pump wave. A dispersion relation in the form of continued fractions involving all space-time harmonics has been obtained for electromagnetic wave propagation in an infinite dielectric medium. The convergence criterion has been established from Poincare's theorem and a 'sonic' region has been defined. The physical parametric processes involved are explained in terms of equivalent non-linear polarization sources postulated by Bloembergen[3].

The second harmonic modulating coefficient ϵ_2 causes strong parametric coupling between the first-order stokes and antistokes wave and also between the fundamental and second-order antistokes wave. Instabilities that occur when the phase velocity of the pump wave exceeds the phase velocity of the signal wave are also considered. When the two pump waves are excited independently by two different generators, the relative phase difference between the waves affects the parametric coupling in the stop band region. The theory which has been developed is used to explain some experimental observations on the non-linear scattering of microwaves by large amplitude density-fluctuations in a plasma.

A letter entitled "Electromagnetic Wave Propagation in a Dielectric Medium Space-Time Modulated by a Non-Linear Pump Wave" was published in the Proc. IEE, Vol. 56, No. 9, pp. 1630, September 1968. A paper entitled "Parametric Interactions in a Dielectric Medium Space-Time Modulated by Two Pump Waves" is now being written and will be submitted for publication soon. An abridged version of this paper was presented at the 1968 International G-AP/URSI Conference held in Boston in September 1968.

1 A. Hessel and A. A. Oliner, IRE Trans. MTT-9, pp. 337-343, 1961.

2 S. T. Peng and E. S. Cassedy, Symposium on Modern Optics, Polytechnic Press, 1967.

3 N. Bloembergen, "Non-Linear Optics", New York, W. A. Benjamin & Co., 1965.

Impedance Behavior of a Short, Cylindrical Probe in a Magnetoplasma - Experimental Investigations - M. Bharathi and B. Rama Rao.

The impedance behavior of an electrically short dipole antenna immersed in a magnetoplasma with the static magnetic field applied parallel to the axis of the antenna has been investigated. The antiresonance behavior at the upper hybrid reson-

ance frequency and the resonance behavior at the cyclotron frequency have been examined carefully. The experimental results have been analyzed using the theories proposed by Balmain and Galejs. The possibility of using this antenna as a diagnostic tool for measuring electron density and collision frequency is being investigated.

The impedance measurements were made at frequencies varying from 300 to 1000 Megacycles with the antenna immersed in a hot-cathode helium discharge at neutral gas pressures ranging from 80 to 400μ of Hg. The plasma discharge tube was placed along the axis of a large solenoid, with the antenna positioned at its center to ensure the uniformity of the magnetic field. The electron density and electron temperature of the plasma were measured independently by a planar Langmuir probe placed in the vicinity of the antenna. The accuracy of these measurements is somewhat questionable for the case of a magnetoplasma because of the difficulty in interpreting the results; these measurements, nevertheless, provide an approximate value for the plasma parameters of the discharge. The experimental results are in good qualitative agreement with theory. At lower neutral gas pressures an additional resonance peak is observed near the cyclotron frequency. This resonance could possibly be due to the ion sheath surrounding the probe; it is not observable at higher pressures because of the increased collision frequency. The theoretical calculations of Galejs predict the existence of such a sheath. The phenomena are now being investigated more thoroughly.

1 K. G. Balmain, IEEE Trans., Vol. AP-12, No. 5, pp. 605-617, September 1964.

2 J. Galejs, Research Report No. 491, Applied Research Lab, Sylvania Electronics System, Waltham, Mass.

Diffraction of Electromagnetic Waves by Moving Striations in a Plasma Column - Experimental and Theoretical Studies - B. Rama Rao and W. A. Saxton.

A paper on this topic was presented at the 1968 Spring URSI meeting held in

Washington D. C. A paper is now being submitted for publication.

A Short Cylindrical Antenna as a diagnostic Probe for Measuring Collision Frequencies in a Collision Dominated Plasma - L. D. Scott and B. Rama Rao.

Work on this problem has been completed. A paper was presented at the 1968 International G-AP/URSI Symposium held in Boston in September 1968. A more detailed version of this paper will be submitted for publication soon.

Plasma Profile Investigations Using a Microwave Cavity Technique - L. D. Scott and B. Rama Rao.

The experimental part of this project has been completed and numerical computations are now in progress to evaluate the effect of plasma inhomogeneity on the cavity resonance characteristics. A report will be prepared as soon as this has been completed.

Experimental Investigations on r. f. Breakdown Effects in Antennas - M. Bharathi and B. Rama Rao.

Antenna r. f. breakdown at cyclotron frequencies is being investigated experimentally. The results will be analyzed with the use of the theory of Lax, Allis, and Brown.

Theoretical Studies on the Circular Loop Antenna in a Plasma Environment - M. Bharathi.

Work in this area was discontinued temporarily during this reporting period.

Theoretical Studies on an Antenna Immersed in a Plasma - A. D. Wunsch.

A cylindrical dipole antenna, immersed in a warm, homogeneous and isotropic plasma, and driven at the center by a delta-function generator, has been treated for the first time as a boundary value problem. The current on the antenna has been determined and found to consist of two parts: a slowly varying component which varies like the current on an antenna in a cold medium, and an oscillatory component. The spatial periodicity of the oscillatory component is of the same order as that of the surface waves launched on an infinite tube containing and surrounded by warm plasma. If the antenna is driven well above the plasma frequency, it has been found that the oscillatory portion of the current is negligible, while if it is driven at slightly above the plasma frequency, the oscillatory portion of the current is dominant. The radiation patterns of the antenna, based on the correct current distribution, have also been determined. It has been found that the shape of the radiation pattern for the electromagnetic waves is the same, as when the antenna is in free space. The driving point impedance of the antenna has been determined by evaluating the current at the terminals of the antenna. A correction has been made to the computed susceptance so as to allow for the idealized (delta-function) driving conditions. A report of this research is scheduled to appear in the September 1968 issue of Radio Science.

The staff now supported in part by this grant includes Professor B. Rama Rao and two part-time students, L. D. Scott and M. Bharathi.