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EFFECTS OF REENTRY ENVIRONMENT ON ANTENNA PERFORMANCE

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The problem of transmission from a vehicle reentering the earths atmosphere has been investigated by the author and his co-workers at Stanford Research Institute during the past several years. The purpose of this program has been to establish general antenna design criteria based on the understanding of the plasma-antenna interaction. Both low-power (linear) and high-power (non-linear) cases have been studied as well as plasma diagnostic and simulation techniques. These tests have been followed by subsequent well-instrumented flight tests to verify the various phenomena investigated in the laboratory. This paper reviews the various laboratory studies carried out and discusses their implication on antenna design and performance.

I WEAK SIGNAL EFFECT OF PLASMA

The effect of a plane wave passing through a uniform plasma can be readily computed. However, in the case of a reentry vehicle, depending upon the vehicle shape and altitude regime a variety of plasma profile and density regimes are encountered. The laboratory experiments involving plasmas formed in an electromagnetically driven shock tube, RF-heated plasma column, and a flame-generated plasma have been directed toward the application of impedance measurement as a plasma diagnostic technique. In general, it is concluded that neither the antenna reflection coefficient measurement nor transmission measurement alone is sufficient for plasma diagnostic. The use of electrostatic probes biased for ion collection either as cylindrical probes, flush probes, or in a wedge configuration gives information about the electron density profile which is necessary for the interpretation of the RF measurements. Flight test data using electrostatic probes on actual reentry vehicles are presented and compared with the theoretically predicted electron density profile.

The effect of the high temperature on the dielectric properties of antenna window material is another area which has been investigated. The increase in the loss tangent has been studied utilizing a carbon arc to heat the window material. Various candidate materials for antenna windows were tested demonstrating the feasibility of the measurement technique. This problem is of importance in designing antennas for space shuttle application, where it is desired to fly the same vehicle many times without refurbishment.

II ANTENNA PERFORMANCE IN THE PRESENCE OF TURBULENT PLASMA

As the reentry vehicle penetrates to altitudes below 30 kilometers, the plasma about the antenna becomes turbulent and overdense. Questions arise concerning the effect of turbulence on antenna radiation pattern as well as mutual coupling effects between various antennas on board the reentry vehicle. To investigate the interaction of electromagnetic waves with turbulent plasma, a turbulent plasma was formed by seeding a premixed ethylene oxygen flame in a combustion chamber and exhausting the plasma through a rectangular nozzle in a low-pressure vessel. The following properties of the turbulent plasma electron density were mapped using the spatial resolution capability of electrostatic probes: (1) mean density; (2) rms amplitude of the fluctuations; (3) power spectral density of fluctuations; (4) mean scale of turbulence, by correlating output of two probes.

The mean and rms amplitude and phase of the reflection coefficient of an X-band slot antenna were measured, as well as radiation pattern and mutual coupling between slots as a function of turbulent plasma parameter. These results indicate that turbulence effect will become important for blunt reentry vehicles with electrically thick boundary layers, but will not be important for sharply pointed vehicles with electrically thin plasma sheath. These measurements demonstrate the futility of trying to obtain nose-on radiation during reentry.

III ANTENNA BREAKDOWN IN HYPERSONIC FLIGHT

When air is heated, breakdown thresholds are reduced by various effects including reduced diffusion of RF-generated electrons. An additional effects is the increase of ionization rates above 3000°K. Measurements made in an electrically driven shock tube of the hot air ionization rates are reviewed, and decrease in breakdown threshold in air up to 6000°K are predicted. The effect of non-uniform near fields of antenna in decreasing the breakdown level are discussed. Briefly, a non-uniform field causes increased gradient in electron density, resulting in higher diffusion rates of electrons out of high field region. A summary of power-handling capability of typical antenna types are presented and measures for increasing the power-handling capability are discussed.