Millimeter Wave Communication through Plasma

Since the dawn of the space age, astronauts returning from orbit have encountered communications blackouts due to plasma encapsulation of the returning spacecraft. Similarly, communication links during ascent have relied on the use of expensive-to-maintain missile communication and tracking annex stations located far from launch facilities to provide the necessary look angles to avoid signal attenuation from rocket motor plasma contrails. In both cases, the issue is one of attenuation of communication signals due to plasma. **Millimeter Wave Communication through Plasma** is a new approach to designing communication systems to extend communications connectivity during launch, and possibly even during re-entry, despite such plasma attenuation.

Irving Langmuir of the General Electric Research Laboratory first observed in 1925 that an electron beam in a discharge tube was being scattered more rapidly than could be accounted for by the simple assumption of collisions between electrons. In 1926, F.M. Penning of the Phillips Research Laboratory in the Netherlands hypothesized the existence of, and confirmed the presence of, high-frequency oscillations in a gas discharge to explain the scattering first observed by Langmuir.[1] In 1928, Langmuir & Tonks (also of the GE Research Laboratory) defined plasma as an ionized gas. In 1929, Langmuir & Tonks confirmed the presence of the high-frequency electrostatic oscillations discovered by Penning, and further derived an equation for the oscillation frequency that is today commonly called either the Langmuir-Tonks frequency, or, more commonly, just the plasma frequency.[2] Plasma frequency is simply "the characteristic oscillation rate for electrostatic disturbances in … plasma."[3] It is the natural collective oscillation frequency of a charge species (electrons, ions, etc.) in plasma.

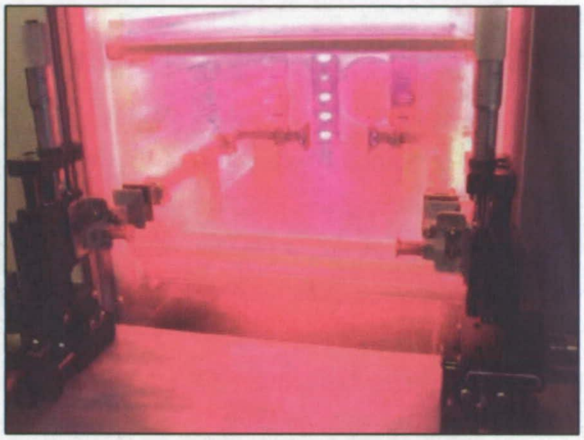

Figure 1 Studying millimeter wavelength signal attenuation thru plasma at Kennedy Space Center inside a plasma chamber

Since dynamics are usually of primary importance in studying plasmas (i.e., ionized gases), research focus is usually placed on just the plasma electrons, rather than on any more massive constituent parts of the plasma. With this assumption, the electron density essentially solely determines the plasma frequency, and plasma frequency is estimated by:

$$\omega_p \cong 5.6 \cdot 10^4 n_e^{1/2} \quad \text{rad/sec}$$

where n_e is the number of electrons per cubic centimeter.[4]

During launch, if the plasma frequency of rocket exhaust is significantly below the operating frequency of the communication link, there is no significant attenuation due to either reflection or pass-through loss from the exhaust cloud to a millimeter wavelength communication link to/from the launch vehicle. The fundamental issue is therefore the electron density of the rocket motor plasma exhaust.

Electron density in rocket plumes has been investigated and has been well documented for plasmas extending beneath rocket engines.[5,6]

Representative electron densities in rocket exhaust plasma fall between $10^8 - 10^{13}$ electrons cm^{-3}, where the lower limits exist at equilibrium exit conditions, such as in the plume; and the highest densities exist at locked conditions found in rocket throats.[7] Hence, for electron densities falling between $10^8 - 10^{13}$ electrons cm^{-3}, plasma frequencies fall between 0.56 Grad/sec to 177 Grad/sec (89.1 MHz to 28.2 GHz). Of course, during the Apollo Program, operating frequencies at millimeter wavelengths were not feasible. Hence, the need for the missile communication and tracking annex stations that currently exist arose. However, for millimeter wave communication systems operating at 35 GHz or higher, operating frequencies are sufficiently above the worst case plasma frequencies such that exhaust plasma reflection and pass-through attenuation effects that could attenuate the communication link are negligible. Operation at such frequencies is now possible, unlike during Apollo.

Similarly, for re-entry, plasmas have additionally been studied and are also understood. However, these plasmas are more intense than the plasmas extending beneath departing launch vehicles. Further research into using millimeter wavelength signals to overcome re-entry plasmas is needed, prior to being able to overcome re-entry communication blackouts entirely.

A future vision of a more cost effective launch capability, involving the use of millimeter wavelength communications through plasma, is emerging in NASA's laboratories. Such communications technology can reduce annual operating costs that have historically been associated with maintaining missile communication and tracking annex stations. The ultimate goal, of reducing the cost associated with access to space, while also improving safety for astronauts through improving communications links, appears feasible.

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Millimeter wave communication through plasma at frequencies of 35 GHz or higher shows promise in maintaining communications connectivity during rocket launch and re-entry, critical events which are typically plagued with communication dropouts. Extensive prior research into plasmas has characterized the plasma frequency at these events, and research at the Kennedy Space Center is investigating the feasibility of millimeter communication through these plasma frequencies.

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