Engineering Notes

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Effects of an Ion-Thruster Exhaust Plume on S-Band Carrier Transmission

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Introduction

THE use of electric thrusters for spacecraft propulsion introduces a plasma medium that can affect the spacecraft-Earth communication link. The study reported here was undertaken 1) to develop models of the effects of an ion-thruster exhaust plume on S-band signals, and 2) to measure the effects. Theoretical models of the plume were obtained[1] to give estimates of the plume effects on the rf signal. Based on knowledge of the plume characteristics and the anticipated experimental configuration,[2] the plasma was modeled as a lossless, isotropic, linear, adiabatic, electron plasma. Using these assumptions, the models predicted that the rf wave would experience 1) a transmission loss due to spreading of the wave by the plume, and 2) a phase shift due to the nonunity refractive index within the plume. The absorption and reflection losses were predicted to be negligible. Details of the interaction models are described elsewhere.[2]

Measurements were performed on a 30-cm diam mercury ion thruster at the Jet Propulsion Laboratory.[3-5] S-band antennas were mounted inside the ion-thruster test chamber, a cw S-band signal was transmitted through the plume (Fig. 1), and the amplitude and phase of the received signal were recorded under various test conditions.

Experiment

Test sequences were designed to study the effects of the plume as a function of rf power level, S-band frequency, wave polarization, and plume plasma density (function of the liquid mercury propellant mass flow rate or "beam current"). Two types of measurements were made: 1) relative signal amplitude as a function of rf frequency (2.1-2.3 GHz) for fixed thruster beam current, rf power level, and polarization; and 2) relative signal amplitude and phase as a function of beam current for fixed rf frequency, power level, and polarization. Measurements were made at two rf power levels in the linear plasma region and for two perpendicular positions of the linearly polarized antennas.

Preliminary measurements indicated the presence of large reflected signals within the test chamber. These reflections were reduced significantly by placing a ring of microwave absorbing material between the two antennas (see Fig. 1). The material had no noticeable effect on the simulated free-space environment (pressure $\sim 10^{-4}$ N/m^2, temperature ~ 80 K).

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Results

Table 1 summarizes the calculated and measured numerical results obtained in the experiment. Figure 2 shows typical results obtained when the beam current is varied. This figure displays the signal attenuation (Fig. 2a) and phase shift (Fig. 2b), where both the mean and standard deviations are calculated at 5-sec intervals. The values are drawn relative to the quiescent level, which occurs when both the main propellant flow and discharge feed of the thruster are off. In

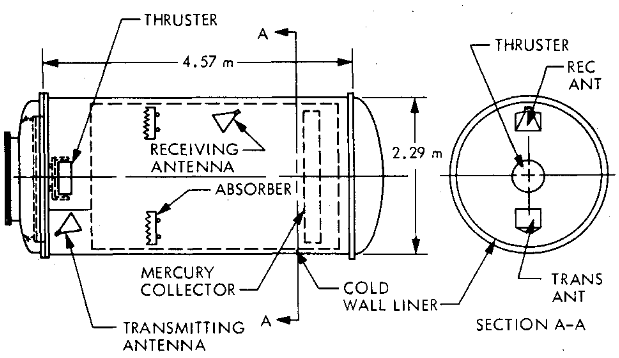

Fig. 1 Ion-thruster test chamber configuration.

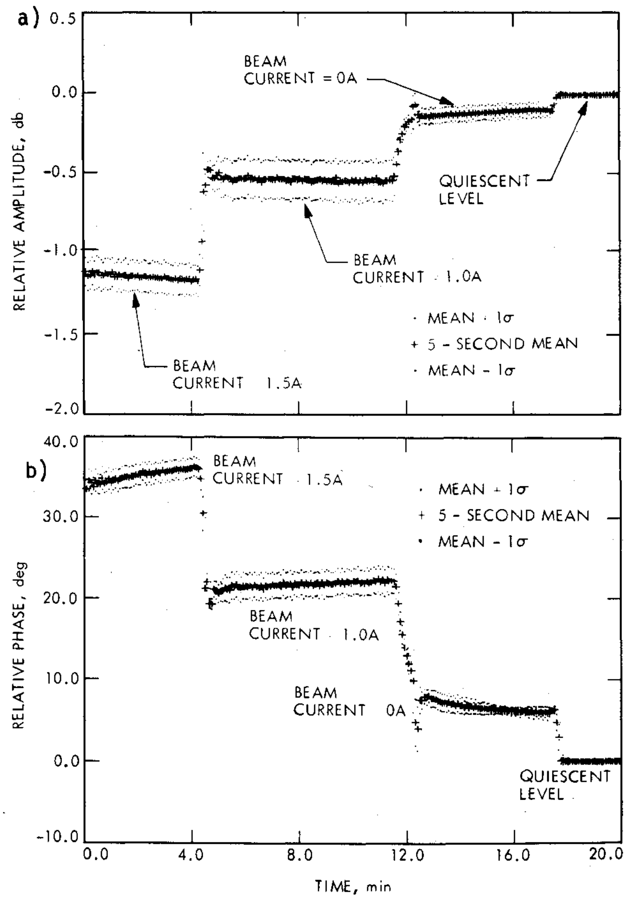

Fig. 2 Relative signal amplitude and phase.

Table 1 Summary of results

Signal parameter	Value at given beam current, A		
	1.0	1.5	1.7
Attenuation, dB			
Calculated	-0.85	-1.07	-1.20
Measured[a]	-0.38 to -0.84	...	...
Measured[b]	-0.30 to -0.50	-0.73 to -1.09	-1.28
Phase shift, deg			
Calculated	29.4	43.4	49.7
Measured[b]	15.5 to 21.9	28.9 to 39.1	43.7

[a] Frequency-averaged. [b] Time-averaged.

Fig. 2, there is a slight attenuation and phase shift at 0 A beam current, apparently because a low-velocity plasma diffuses out of the thruster from the discharge feed system. The attenuation and phase shift values of Fig. 2 are included in the "time-averaged" values shown in Table 1.

The standard deviation shown in Fig. 2 provides a measure of signal amplitude and phase fluctuations. In almost all cases, the standard deviation was the largest when the beam current was 1.0 A. For the case shown in Fig. 2a, the amplitude standard deviations are 1.3% and 0.9% for the 1.0- and 1.5-A cases, respectively, or about 0.1 dB in each case. The average amplitude fluctuations would have negligible effect on the performance of either the phase tracking loop or the data detection of typical spacecraft receivers.[6] The phase standard deviation of the 1.0-A case in Fig. 2b is about 1.5°, which would produce less than 0.1 dB degradation under the worst-case ratio of phase bandwidth to loop bandwidth.

Within the limited set of measured data, the attenuations and phase shifts apparently were insensitive to the rf frequency, the rf power levels, and the polarizations used in this experiment. However, more data must be taken before these effects can be evaluated accurately.

Conclusions

The results show that an S-band signal passing through an ion-thruster plume is reduced in amplitude and advanced in phase, in agreement with the simplified mathematical models. The steady-state signal attenuation levels measured in this experiment have a significant impact on the communication link performance, e.g., data rate or bit-error rate capability. In addition, multiple-thrust configurations could increase the plume plasma density, which could produce a larger signal attenuation than is experienced in the single-thruster case. The steady-state signal phase shift has no direct effect on link performance. The steady-state fluctuations in signal amplitude and phase have little effect on communication link performance at this frequency. Jumps in phase resulting from rapid changes in beam current could cause the receiver loop to lose lock, and so changes in beam current should be made gradually to allow the changing phase to be tracked by the receiver. This study confirms that the thruster plume can have a significant effect on S-band communication link performance; hence the plume effects must be considered in S-band link calculations when electric thrusters are used for spacecraft propulsion.

Acknowledgment

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Improving the Performance of Missiles by Balance Loads

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Introduction

WHEN a missile changes its direction, inertial forces act on its body. As the strength of the missile body is limited, the missile is limited in its performance, too.[1] In order to improve its performance, it is designed so that balance forces produced by a device located in the missile will operate on the missile body when it is affected by the inertial forces. These balance forces are designed to lower the effect of the inertial forces to the maximum extent.

A missile possessing the proposed system will operate better in comparison with one without it. The design of such a system for a given missile is very complicated, and serious problems have to be overcome. A somewhat unrealistic example of design of such a system in a schematic missile will clarify the basic principles of design.

Forces Acting on the Missile

It is assumed that the discussed missile changes its direction in a cycle movement in a constant radius (Fig. 1). Such a cycle movement of the missile is composed of two different movements: the overall cycle movement around the center of movement, and the self-cycle movement around the center of the mass of the missile. It is assumed that two jets put the missile into the cycle movement; the first is located in the mass center, and the second one is off center at a distance e. The jets are directed perpendicularly to the length of the missile (Fig. 1). In order to change the missile direction, the two jets have to work for a very short time Δt at a strength given by

$$F_1 = MV^2/R - JV/e\Delta tR \tag{1}$$

$$F_2 = JV/e\Delta tR$$

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