RFI Measurements at UHF on a Pulsed Plasma Thruster

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EXPERIMENTAL Pulsed Plasma Thrusters (PPT) were flown aboard the Lincoln Experimental Satellite LES-6 to provide the thrust necessary for a stationkeeping experiment. The thrusters were manufactured by Fairchild-Hiller, Republic Division, and provided an approximate 6 μlb-sec impulse from each discharge of 1.85 joules of electrical energy. A Radio-frequency interference (RFI) specification was drawn up along with a measurement procedure. The RFI specification, measurement procedure, and measured results are the subjects of this Note.

The thruster nozzle and teflon propellent subsystem are described in Ref. 1. Thrust from the PPT was provided by the acceleration of gaseous ionized teflon through a nozzle (horn). The igniter plug initiated a conductive discharge between the anode and cathode which vaporized and ionized some of the teflon fuel element. The ionized particles were accelerated by two mechanisms, one being the gas pressure difference between the ionized particles and free-space and the other due to magnetic forces set up by the conduction current. The process is inherently noisy and thus arises the concern over RFI effects on the rf transponder aboard.

The rf transponder operated at an assigned uplink frequency in the neighborhood of 300 MHz with a 100 kHz bandwidth. The receiver contained a bandpass limiting IF amplifier that had approximately 60 db of dynamic range and limited on front end input noise. Receive signals equal in power to the total threshold noise power would "capture" approximately one-half of the downlink transmit power.

RFI Specifications

An RFI specification was established from information about the nature of the signals to be transmitted over the communications link and from the rf transponder characteristics. Because of the limiting characteristics of the transponder, signals above the threshold noise would share power with any downlink signals present in the band and in fact if the interfering signals looked like high-level white noise in the transponder band they could cause severe decreases in signal down link power (i.e., the noise power capturing the limiter). The communication link signal modulation most sensitive to temporary interruptions was a narrow band FM signal.† Experiments run over a simulated communications link indicated that signal interruptions in excess of 50 μsec duration caused interference to the FM communications link. This set a basic requirement that there be no loss of signal for time intervals greater than 50 μsec. The pulse repetition frequency in operation was 0.67 pps maximum, which was considered not sufficiently large to further affect the FM signal.

The noise pulses must be less than 60 db above the receiver threshold noise point given by

$$Pt = (KTB) \times (NF)$$

where K = Boltzmann's constant 1.38×10^{-16} erg/deg, T = absolute temperature °K, B = bandwidth in Hz, NF = system noise figure.

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† 5–8 kHz peak deviation.

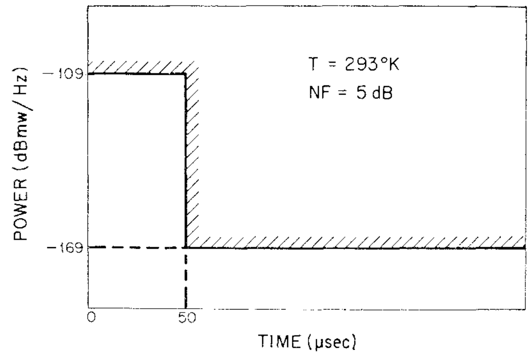

Fig. 1 LES-6 RFI specification.

For a transponder at 293°K having a 5 db noise figure, the threshold noise is −169 dbmw/Hz. The interfering pulse, however, may exceed Pt for periods up to 50 μsec but in no case exceed Pt + 60 db, the level at which the receiver saturates, for the ensuing recovery time is longer than 50 μsec. The RFI specification is summarized in Fig. 1.

Measurement Procedure and Results

The problem of making meaningful measurements of the interferring signal is not trivial. Consider the thruster as a transmitter of energy. To assess the RFI effects on the transponder, both the transmitter (thruster) signal and the coupling to the spacecraft antennas must be characterized either separately or jointly. The response of a filter driven by the thruster signal can be conveniently measured. If the filter bandwidth and center frequency are set equal to those of the transponder, the interference signal resulting from the thruster firing can be measured.

The rf coupling between the plasma and the spacecraft antenna system will in general depend upon plasma radiation characteristics and the near field characteristics of the receive antenna. This property can be measured in an anechoic chamber or some other suitable antenna measurement environment. The spacecraft antenna in the case of LES-6 is comprised of the spacecraft body itself (see Fig. 2). Thus the coupling measurements should be made when both the spacecraft antenna and the thruster are attached to the spacecraft in the flight orientation. Since the PPT operates only in a hard vacuum we require a vacuum anechoic chamber large enough to incorporate the satellite.

For the LES-6 program, no such anechoic chamber was available. However, as a first cut experiment, a prototype PPT was mounted on the LES-6 antenna model which in turn was placed inside an 8-ft-diam, cylindrical vacuum tank lined with a Salisbury screen absorber. The Salisbury screen absorber is comprised of a thin sheet of "space cloth" (Resistance = 366 Ω/sq) absorber material backed by a short circuit one quarter wavelength away. This absorber appears as the free-space wave impedance to a plane wave incident at wavelength λ_0 and completely absorbs the free-space

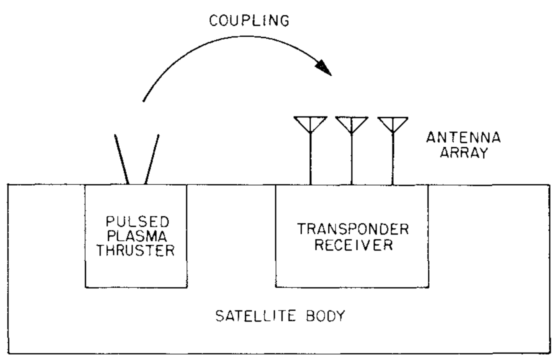

Fig. 2 PPT RFI coupling.

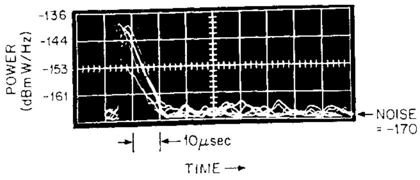

Fig. 3 PPT RFI measurements.

wave. Waves at λ_0 incident at an angle with respect to the normal, have only the normal component completely absorbed. For the PPT, RFI experiments, a significant portion of the radiated wave was not normal to the absorber and some ringing took place within the cavity formed by the vacuum tank walls. This ringing was due to the presence of high-order coaxial modes propagating parallel to the absorber sheet. RFI measurements were made initially on a PPT mounted in the flight configuration with respect to the antennas. The results of the experiment were in error for the chamber acted as an echo box to yield erroneous time duration RFI measurements.

Two successive experiments were subsequently performed. One used a vacuum bell jar to house the PPT and a monopole antenna cut for 300 MHz ($VSWR = 1.35{:}1$) mounted both inside and outside the jar. The walls of the measurement area were lined with the broadband absorber blocks of the type used in large anechoic chambers to prevent reflections of the rf energy. The effects of antenna coupling were proved to be small in this experiment for the amplitude of the RFI was essentially independent of antenna location. Finally, RFI measurements were made in a 4 ft diam vacuum tank completely lined with broadband ferrite absorber material.‡ This environment rendered measurements free from any chamber resonance effects. Measurements were made of RFI time duration above the measurement threshold as seen in a 100 kHz bandwidth. The amplitude results of the three experiments agreed to within a few db/Hz and the time duration results varied from 40 μsec in the first experiment§ to 10–15 μsec in the last experiment. Although there were some uncertainties in the discharge time of the thruster, it was expected to be more in the neighborhood of 2–3 μsec rather than 10–15 μsec. This additional stretching is attributed to the (relatively) narrow bandwidth of observation. The answers, nonetheless, were sufficient for the LES-6 purposes. Figure 3 gives the RFI power vs time recorded from measurements on five successive firings in the 4-ft-diam ferrite lined chamber. The center frequency was 300 MHz and the Bandwidth 100 kHz. The peak power varied from −139 dBmw/Hz to −149 dBmw/Hz with successive firings of the plasma thruster.

Conclusions

A technique has been evolved to measure RFI emanating from a Pulse Plasma Thruster. This involves the measurement of the amount of r.f. power received at an antenna having a plasma in the near field. It is desirable to make the measurement in a vacuum anechoic chamber with the plasma and receiving antenna in their flight orientation. If this is not possible a good estimation of the RFI power may be obtained by using smaller vacuum anechoic chambers of low electrical Q to house the PPT and a test antenna.

Reference

[1] Guman, W. J. and Nathanson, D. M., "Pulsed Microthruster Propulsion System for Synchronus Orbit Satellite," *Journal of Spacecraft and Rockets*, submitted for publication.

‡ Typically 15 db return loss from 50 MHz to 15 GHz.
§ The additional 25–30 μsec duration due to ringing.

Generalized One-Dimensional, Compound Compressible Nozzle Flow

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Nomenclature

A	= area
a,b	= constants, b/ρ_P and r/P^n, respectively
C	= constant for perfect gas
$E = E(\psi)$	= energy of a streamline
H_0,h	= stagnation and static enthalpy, respectively
$\Delta H_c, \Delta H_v$	= heats of combustion and vaporization, respectively
K	= flow coefficient, constant
$\mathfrak{M}$	= molecular weight
$\dot{m}$	= mass flow rate
O/F	= oxidizer/fuel flow ratio
P	= pressure
r	= radial coordinate, or burning rate
R	= radius
R_g	= perfect gas constant
T	= temperature
U,V,W	= radial, tangential, and axial velocities, respectively
ϵ_c	= contraction ratio, A_c/A_t
γ	= specific heat ratio
$\Gamma = \Gamma(\Psi)$	= $V \times r$
Ψ	= stream function $= \int_0^{\dot{m}(r)} \frac{d\dot{m}}{\dot{m}_T}$
ω	= angular velocity
ρ	= density

Subscripts

0	= stagnation condition
1,2	= inner and outer zones, respectively
c,cl,I	= chamber, centerline, and injector, respectively
f,g,L,P	= flame gas, liquid, and propellant, respectively
R,T,t,w	= reservoir, total, throat, and wall, respectively

Introduction

THERE are occasions in the design of nozzles when it is convenient to treat flows in which the entropy (i.e., total pressure, total temperature) varies normal to the streamlines but is conserved along the streamlines. In the case when two-dimensional effects are of secondary importance, the flows from rotating rocket motors or bypass turbojet engines, for example, can be treated by special one-dimensional techniques. Some of the ground work has been laid for such analyses.[1–4] This paper describes a unified theory for which the specific problems listed earlier are subsets and presents specific examples of its uses.

Analysis

The properties of the flowfield are assumed to be known at the nozzle inlet (see Fig. 1a). It is desired to evaluate the radial distribution of the flow variables at the throat plane and to determine the radius, R_t, required to choke the flow as defined by the initial conditions. The following restrictions (some of which can be removed as discussed later) are placed on the flow for the flow for the initial develop-

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