## **General Disclaimer**

## One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

## 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.<sup>1</sup> 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.<sup>2</sup> Plasma frequency is simply "the characteristic oscillation rate for electrostatic

disturbances in ... plasma.<sup>3</sup> 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:

$$\omega_p \cong 5.6 \cdot 10^4 n_e^{1/2} \qquad \text{rates}$$

rad/sec

where  $n_e$  is the number of electrons per cubic centimeter. <sup>4</sup>

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

2008 Space and Missile Defense Conference, Huntsville, AL. 11-14 August 2008

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.<sup>5,6</sup>

Representative electron densities in rocket exhaust plasma fall between  $10^8 - 10^{13}$  electrons cm<sup>-3</sup>, 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.<sup>7</sup> Hence, for electron densities falling between  $10^8 - 10^{13}$  electrons cm<sup>-3</sup>, 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.

Contact: Dr. Gary L. Bastin, ASRC Aerospace, Mailstop: ASRC-10, Kennedy Space Center, FL 32899 (Gary.L.Bastin@nasa.gov, (321) 867-9275) http://www.ustdc.com

This ongoing research is sponsored by NASA's Kennedy Space Center under the Emerging Communications Technologies project.

GB082008

- ,

<sup>&</sup>lt;sup>1</sup> E.H. Holt and R.E. Haskell, *Foundations of Plasma Dynamics*. New York: The Macmillan Company, 1965, pp. 8-9. <sup>2</sup> Holt and Haskell, p. 9.

<sup>&</sup>lt;sup>3</sup> Wulf B. Kunkel, Plasma Physics in Theory and Application. New York: McGraw-Hill, 1966, p. 7.

<sup>&</sup>lt;sup>4</sup> Wulf B. Kunkel, Plasma Physics in Theory and Application. New York: McGraw-Hill, 1966, p. 7.

<sup>&</sup>lt;sup>5</sup> Ping Zhang and Wanjun Bi, "Investigation on Microwave Signal Attenuation by Solid Propellant Flames and Plumes." *AIAA PAPER 93-2456*, AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, 29th, Monterey, CA, June 28-30, 1993.

<sup>&</sup>lt;sup>6</sup> David A. Cooper and Robert A. Frederick, "The Measurement of Electron Density in a Rocket Motor Plume." *AIAA PAPER 93-2453*, AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, 29th, Monterey, CA, June 28-30, 1993.

<sup>&</sup>lt;sup>7</sup> David A. Cooper and Robert A. Frederick, "The Measurement of Electron Density in a Rocket Motor Plume." AIAA PAPER 93-2453, p. 6, June 1, 1993, AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, 29th, Monterey, CA, June 28-30, 1993.

				08-478		
REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188		
The public reporting burden for this collection data sources, gathering and maintaining the any other aspect of this collection of informat for Information Operations and Reports (070- notwithstanding any other provision of law, no valid OMB control number.	of information is estimated to average 1 data needed, and completing and reviewir ion, including suggestions for reducing thi -0-188), 1215 Jefferson Davis Highway, S o person shall be subject to any penalty for THE ABOVE ADDRESS	hour per response, ng the collection of s burden, to Depar Suite 1204, Arlingto or failing to comply	including the information tment of De n, VA 2220 with a collect	he time for reviewing instructions, searching existing bard comments regarding this burden estimate or efense, Washington Headquarters Services, Directorate 12-4302. Respondents should be aware that ction of information if it does not display a currently		
1. REPORT DATE (DD-MM-YYYY) 2. REPORT TYPE			3. DATES COVERED (From - To)			
	presentation			August 11-14, 2008		
4. TITLE AND SUBTITLE Millimeter Wave Communication Through Plazma			5a. CON	TRACT NUMBER		
			NAS10-	03006		
			5b. GRANT NUMBER			
			5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S) Gary Bastin, ASRC Aerospace			5d. PROJECT NUMBER			
			5e. TASK NUMBER			
			5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) ASRC Aerospace ASRC-48 Kennedy Space Center, FL 32899				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AG	ENCY NAME(S) AND ADDRESS(E	S)		10. SPONSORING/MONITOR'S ACRONYM(S)		
National Aeronautics and Space A	dministration			NASA/KSC		
Kennedy Space Center, FL 32899				11. SPONSORING/MONITORING REPORT NUMBER		
12. DISTRIBUTION/AVAILABILITY S	TATEMENT			I		
13. SUPPLEMENTARY NOTES						
14. ABSTRACT Millimeter wave communication th connectivity during rocket launch prior research into plasmas has cha investigating the feasibility of mill	hrough plasma at frequencies of and re-entry, critical events whic aracterized the plasma frequency limeter communication through t	35 GHz or hig ch are typically y at these even these plasma fi	gher show y plaguec ts, and re requencie	vs promise in maintaining communications d with communication dropouts. Extensive esearch at the Kennedy Space Center is es.		
15. SUBJECT TERMS plasma, millimeter, communicatio						
16. SECURITY CLASSIFICATION OF	17. LIMITATION OF	18. NUMBER OF PAGES	19b. NA	19b. NAME OF RESPONSIBLE PERSON		
a REPORT IN ABSTRACTIC T	ABSTRACT		Dr. Gar	Dr. Gary Bastin		
			19b. TEI	19b. TELEPHONE NUMBER (Include area code)		
		1	(321) 867-9275			
				Standard Form 298 (Rev. 8-98)		

St	andard	rorm	298	(Rev.	8-99
Pre	escribed by	y ANSI S	Std. Z3	9-18	