Defense Systems
Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Radio Frequency (RF) Attenuation of Non-Earth Elements

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ABOUT DSIAC

The Defense Systems Information Analysis Center (DSIAC) is a U.S. Department of Defense information analysis center sponsored by the Defense Technical Information Center. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

DSIAC serves as the national clearinghouse for worldwide scientific and technical information for weapon systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. We collect, analyze, synthesize, and disseminate related technical information and data for each of these focus areas.

A chief service of DSIAC is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. For more information about DSIAC and our TI service, please visit www.DSIAC.org.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on the attenuation of radio frequency energy propagating through gases and liquids that are not components of Earth's atmosphere, as most data on propagation loss in RF are for compounds typically found in the atmosphere. DSIAC contacted Georgia Tech Research Institute (GTRI) to help respond to the inquiry, and GTRI subject matter experts (SMEs) researched and compiled a list of relevant literature sources. The best source for data about gases not present in Earth's atmosphere came from publications where gases making up the atmosphere of other planets within our solar system were studied. A list of relevant sources and the contact information of a SME who specialized in characterizing materials over a wide range of frequencies in a laboratory environment were delivered to the inquirer.

Contents

1.0 TI Request

1.1 INQUIRY

Is there data available on radio frequency (RF) attenuation as a function of frequency for gases, liquids, and solids that are not part of Earth's atmosphere?

1.2 DESCRIPTION

The inquirer was specifically interested in information in the form of links to articles, downloadable content, and scanned copies of articles, tables, graphs, etc. The inquirer also noted that most data on propagation loss for RF are for compounds typically found in the atmosphere.

2.0 TI Response

DSIAC contacted subject matter experts (SMEs) at Georgia Tech Research Institute (GTRI) working in electromagnetic materials. A GTRI SME performed a literature search for reports and studies regarding RF attenuation in the Defense Technical Information Center (DTIC) Research and Engineering (R&E) Gateway, though not much was found relating to non-Earth elements (see the DTIC bibliography in the Appendix for two articles of interest that were found via the DTIC R&E Gateway search). An additional response, based on the expertise of GTRI SME David Reid, is provided next.

For solid materials, propagation loss can be calculated from the electromagnetic constitutive properties (complex permittivity $\varepsilon = \varepsilon_r \varepsilon_o = \varepsilon_o(\varepsilon_r' - j\varepsilon_r'')$, and permeability $\mu = \mu_r \mu_o = \mu_o(\mu_r' - j\mu_r'')$) of the material. As RF energy propagates through a material for a distance t, the propagation loss is

$$e^{-\alpha t},$$

$$\text{where } \alpha = -2\pi f \sqrt{\varepsilon_o \mu_o}\,(a^2 + b^2)^{1/4} \sin\left(\tfrac{1}{2}\tan^{-1}\left(-\tfrac{a}{b}\right)\right),$$

in which $a = (\varepsilon_r' \mu_r' - \varepsilon_r'' \mu_r'')$, $b = (\varepsilon_r' \mu_r'' + \varepsilon_r'' \mu_r')$, and f is frequency. Note that in many references, the dielectric loss is specified in terms of the loss tangent, $\tan\delta = \varepsilon_r'' / \varepsilon_r'$.

Tabulated data for the permittivity and permeability of a wide variety of materials are available in literature. One commonly cited resource containing material properties for a range of dielectric materials is the textbook *Dielectric Materials and Applications* [1]. An extensive list of materials commonly used in radar absorbing materials can be found in the textbook *Electromagnetic Composites: Models, Measurement, and Characterization* [2]. The MatWeb material property online database [3] also has dielectric constant data for a variety of materials.

Data on the attenuation of RF energy propagating through gases and liquids that are not components of Earth's atmosphere are not as widely available from publicly-accessible sources. The attenuation of materials in gas or liquid state is often more dependent on temperature and pressure in the gases than the attenuation of solid materials, although the properties of solid materials are also somewhat temperature dependent. Tabulated data for some common liquids are provided in *Dielectric Materials and Applications* [1].

The best sources for data about gases not present in Earth's atmosphere are publications which focus on gases that make up the atmosphere of other planets in our solar system. A good collection of these properties is available in the Planetary Atmospheres database [4] hosted by Georgia Tech. However, the available data are far from exhaustive.

If a specific list of materials and frequencies is supplied, material properties in published literature can be located or the materials can be characterized in a laboratory environment.

An article that may be of interest, "Fundamental Limitations Caused by RF Propagation" by R. K. Crane [5], was found using the National Aeronautics and Space Administration (NASA) as one of the key words. It details how propagation phenomena affects the designs of RF transmission systems.

REFERENCES

[1] Von Hippel, A. *Dielectric Materials and Applications*. Boston, MA: Artech House, 1 December 1995.

[2] Moore, R. *Electromagnetic Composites: Models, Measurements, and Characterization*. Second edition, New York, NY: McGraw-Hill Education, 25 March 2016.

[3] MatWeb. "MatWeb, Your Source for Materials Information." http://matweb.com/, accessed April 2016.

[4] Planetary Atmospheres at Georgia Tech. "Papers." http://planetary.ece.gatech.edu/papers.html, accessed April 2016.

[5] Crane, R. K. "Fundamental Limitations Caused by RF Propagation." *Proceedings of the IEEE*, vol. 6, no. 2, pp. 196–209, https://ieeexplore.ieee.org/document/1456220, February 1981.

APPENDIX: DTIC Bibliography

Advisory Group for Aerospace Research and Development Neuilly-Sur-Seine. "Radio Wave Propagation Modeling, Prediction and Assessment (I'evaluation, La Prevision Et La Modelisation Des Ondes Hertziennes)." France, 1 January 1990.

Brown, D. M., and M. B. Wells. "A Literature Review of Millimeter and Submillimeter Radiation Absorption and Scattering in the Atmosphere." Radiation Research Associates Inc., Fort Worth, TX, 1 October 1978.

BIOGRAPHY

DAVID REID, PH.D., is a principal research engineer and head of the Electromagnetic Materials and Measurements Branch of GTRI's Advanced Concepts Laboratory. His research interests include the electromagnetic characterization of materials and structures and the design of engineered materials. Dr. Reid has developed and delivered custom material characterization systems for labs throughout the country and designed validation and verification standards for the focused beam measurement system. He has worked to understand the mechanisms for uncertainty in existing measurement fixtures and develop techniques to reduce this uncertainty for various systems. He has also worked on the design of engineered materials and surfaces, using computational electromagnetics tools to tailor the material properties to meet desired specifications and accurately predict performance. Dr. Reid teaches continuing education classes on electromagnetic materials and measurements.