NASA/TM—2012-217267

Model of the Radio Frequency (RF) Excitation Response from Monopole and Dipole Antennas in a Large Scale Tank

Jeffrey D. Wilson and Gregory A. Zimmerli
Glenn Research Center, Cleveland, Ohio

January 2012

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 443–757–5803

- Telephone the NASA STI Help Desk at 443–757–5802

- Write to:
  NASA Center for AeroSpace Information (CASI)
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2012-217267

Model of the Radio Frequency (RF) Excitation Response from Monopole and Dipole Antennas in a Large Scale Tank

Jeffrey D. Wilson and Gregory A. Zimmerli
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

January 2012

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available electronically at http://www.sti.nasa.gov

Model of the Radio Frequency (RF) Excitation Response From Monopole and Dipole Antennas in a Large Scale Tank

Jeffrey D. Wilson and Gregory A. Zimmerli
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Summary

Good antenna-mode coupling is needed for determining the amount of propellant in a tank through the method of radio frequency mass gauging (RFMG). The antenna configuration and position in a tank are important factors in coupling the antenna to the natural electromagnetic modes. In this study, different monopole and dipole antenna mounting configurations and positions were modeled and responses simulated in a full-scale tank model with the transient solver of CST Microwave Studio (CST Computer Simulation Technology of America, Inc.). The study was undertaken to qualitatively understand the effect of antenna design and placement within a tank on the resulting radio frequency (RF) tank spectrum.

Introduction

In order to determine the amount of liquid remaining in a propellant tank using the radio frequency mass gauge (RFMG) method, it is necessary to mount an antenna inside the tank, excite the electromagnetic modes, and measure the eigenmode frequencies (Ref. 1). An important aspect of this procedure is the design and position of the antenna inside the tank. Ideally, the antenna should be mounted in a position to strongly excite as many of the lower eigenmodes as possible. In this investigation, different monopole and dipole antenna mounting configurations and positions were modeled and responses simulated in a tank model using the transient solver of CST Microwave Studio (CST Computer Simulation Technology of America, Inc.). Three different monopole mounting configurations were investigated: top-mounted on the center of the tank lid, side-mounted on the side wall of the tank, and center-mounted on a central metal rod running from the top to the bottom of the tank. Dipole antenna simulations were performed in the center-mounted configuration with both parallel and transverse mountings of the antenna with respect to the long axis of the tank.

Analysis

The tank, in the shape of a cylinder with rounded edges (Fig. 1), was modeled with the transient solver of Microwave Studio. This solver calculates the time-varying field distribution that results from excitation with a Gaussian pulse at the input port. When a steady state solution is reached, the S-parameters defining the transmission characteristics as a function of frequency are calculated with a Discrete Fourier Transform (Ref. 2).

The tank has a length $L = 472.9$ cm and a radius of 91.0 cm, and corresponds to actual dimension of a tank being used for antenna-mode coupling tests of the RFMG method. The results of those tests will be reported in a separate publication. The surfaces of the tank were modeled as perfect conductors. After the tank and antenna geometries were modeled as described below, the solver was used to compute the steady state response of the return loss spectrum in the frequency range 100 to 200 MHz.

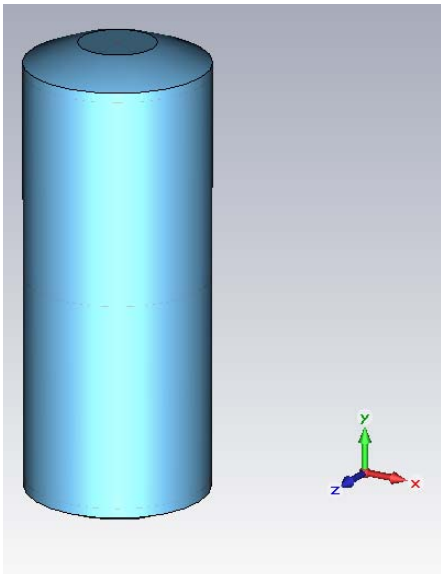

Figure 1.—Outer view of the tank model.

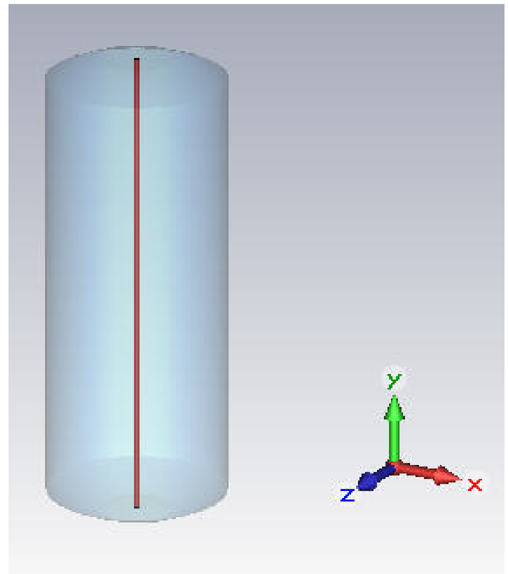

Figure 2.—Inner view of the tank model with off-center mounting rod.

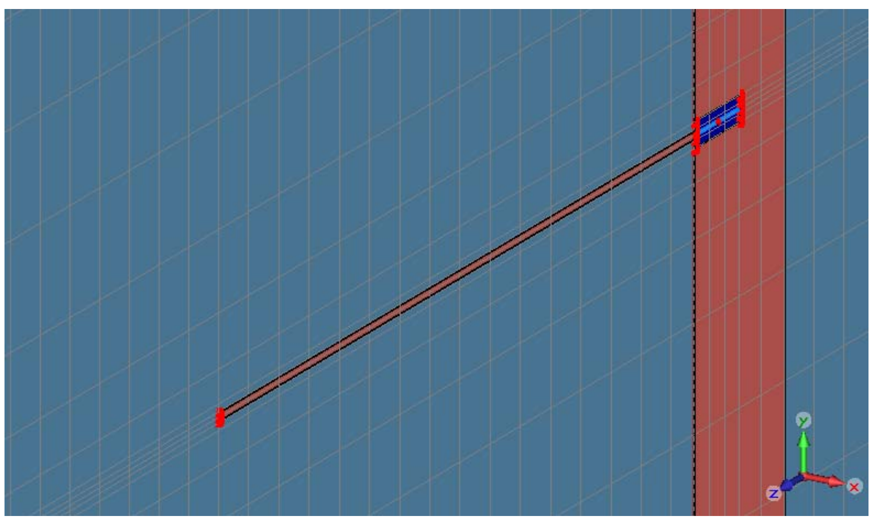

Figure 3.—Mesh at monopole antenna in center-mounted configuration. The base of the monopole is flush with the outer surface of the center mounting rod.

Monopole Antenna Configurations

For the center-mounted monopole configuration only, a perfect conducting rod of 3.8 cm diameter runs along the long axis of the tank (Fig. 2). Figure 3 shows the geometry of the monopole antenna for the center-mounted configuration with the Microwave Studio mesh with a 25 cm monopole. The position of the antenna is halfway down from the top of the tank.

A close-up of the antenna excitation port is shown in Figure 4. This is designated in Microwave Studio as an impedance element discrete port (S-parameter type) and is used as the RF feed point source for the antenna. It is modeled as a perfect conducting wire inside a coaxial cavity and provides an input power of one watt (Ref. 2). This type of feed port is also used in the dipole antenna simulations.

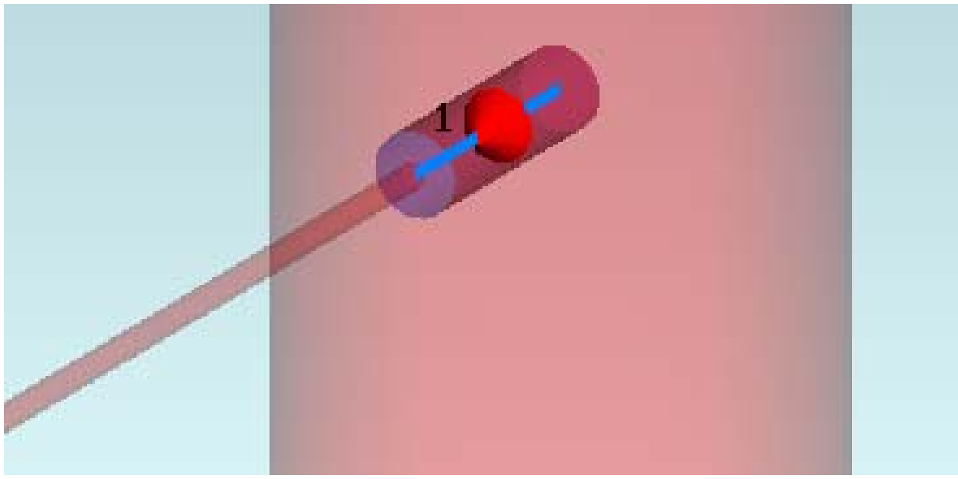

Figure 4.—Close-up of monopole antenna excitation port.

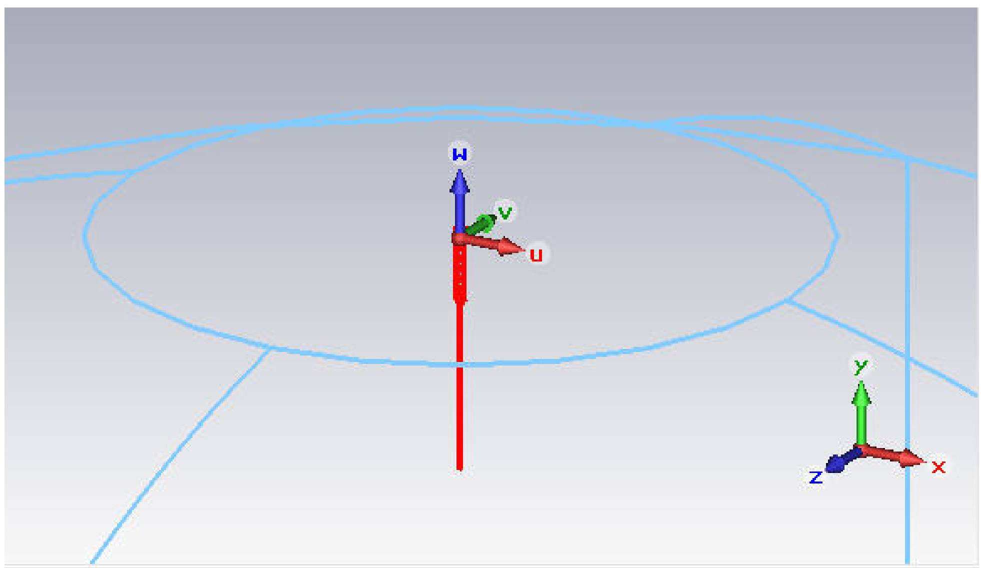

Figure 5.—Top-mounted monopole antenna configuration.

In the side-mounted monopole configuration, the same 25 cm antenna design is used, with the base of the monopole flush with the inner surface of the side wall of the tank, and the center rod is not included in this tank model. Two mounting positions for the antenna were simulated, one at y = L/2, and another at the y = L/3 position.

In the top-mounted configuration, the center rod is also removed from the tank model and a 25 cm monopole antenna is inserted through the center of the top of the tank as shown in Figure 5. A local coordinate system u-v-w was defined in Microwave Studio overlaying the global coordinate system x-y-z to position the antenna.

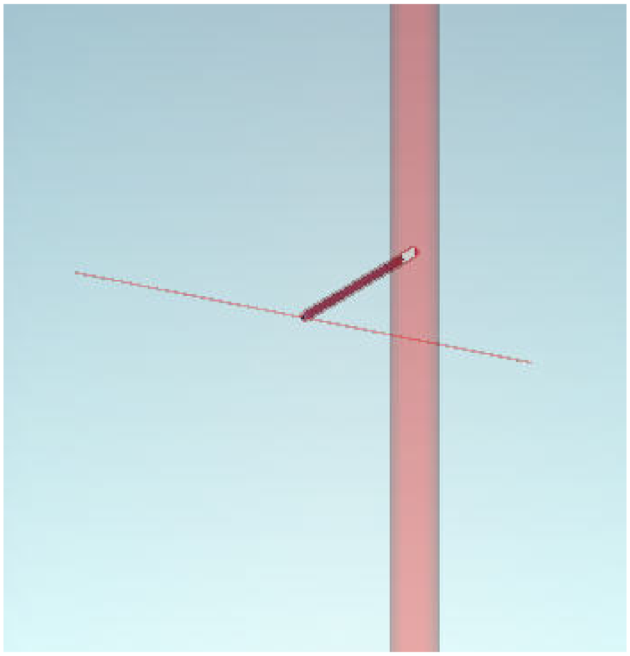

Figure 6.—Dipole antenna, transverse orientation.

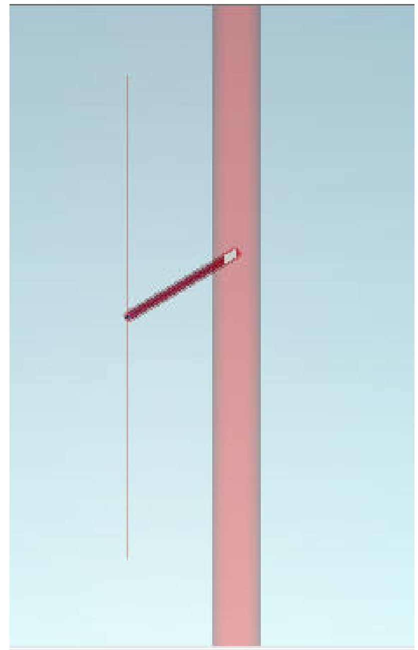

Figure 7.—Dipole antenna, parallel orientation.

Dipole Antenna Configurations

The response from a dipole antenna was simulated using the same tank and rod, but with the rod displaced 11.4 cm in the negative z-direction from the center axis. Two antenna orientations were simulated: Figure 6 shows the transverse orientation and Figure 7 shows the parallel orientation of the dipole antenna. The dipole length is 40.6 cm and it is positioned 15.2 cm in the positive z-direction from the rod.

Results

Top-Mounted Monopole Antenna Configuration

The simulated return loss from the top-mounted configuration is shown in Figure 8. (The responses are plotted from 100 to 200 MHz to match the region of experimental interest.) Only the TM modes are excited in this frequency range as can be seen by the corresponding electric field and magnetic field mode amplitudes in Appendix A.

Side-Mounted Monopole Antenna Configurations

The simulated return loss for the two side-mounted monopole antenna configurations are shown in Figure 9 (antenna at $y = L/3$) and Figure 10 (antenna at $y = L/2$). The model predicts fewer mode excitations and a weaker amplitude in the return-loss spectrum than in the top-mounted case. Experimentally, we observe a much better return-loss spectrum than that predicted by the side-mounted model. The source of the discrepancy is not clear, but indicates that the antenna-tank coupling model can only be used to make qualitative predictions.

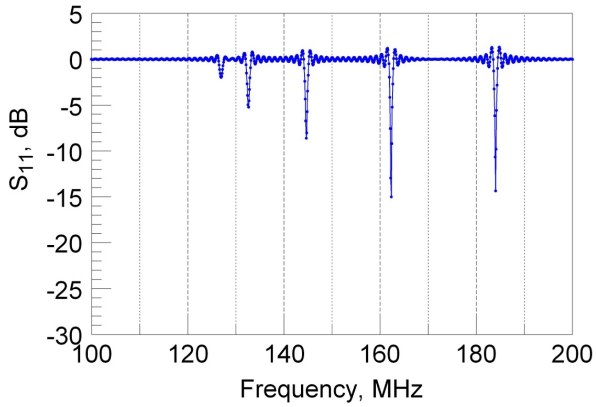

Figure 8.—Return loss with top-mounted monopole antenna configuration.

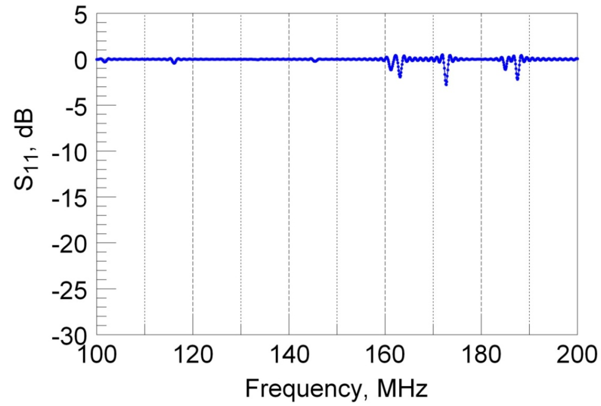

Figure 9.—Return loss with side-mounted monopole antenna configuration mounted one third from the top (y = L/3).

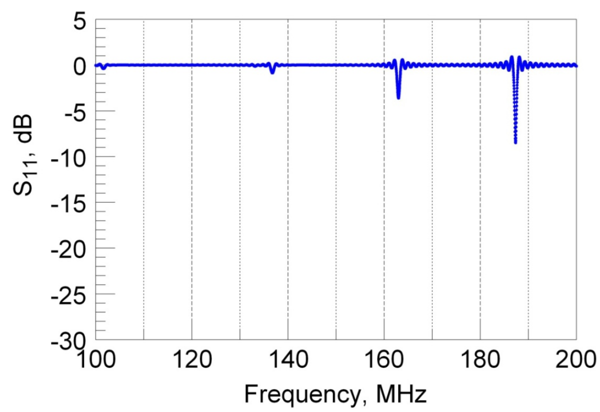

Figure 10.—Return loss with side-mounted monopole antenna configuration mounted one half from the top (y = L/2).

Center-Mounted Monopole Antenna Configurations

The center-mounted configuration was further investigated by varying the length of the monopole from 5 to 25 cm. It was found that return loss peaks at the same frequencies for each monopole length, but the strength of the response generally increases as the monopole length increases. The position of the 25 cm monopole antenna within the tank was also investigated. The results for y = L/16 to L/2 are shown in Figures 11 to 18.

From Figures 11 to 18, the model predicts the strongest responses to occur at eigenfrequencies of 126.4, 156.1, 160.3, and 187.2 MHz. As expected, it is seen that the center-mounted configuration has different eigenfrequencies than the top- and side-mounted configurations, due to the introduction of the center bar into the tank. There is also a wide variation in response strength depending on antenna position, with the 7/16 position being the only one to have a predicted return loss of at least –5 dB for each of these eigenfrequencies. The electric and magnetic field amplitudes of the corresponding eigenmodes for the 7/16 case are shown at a cross section of the tank in Appendix B.

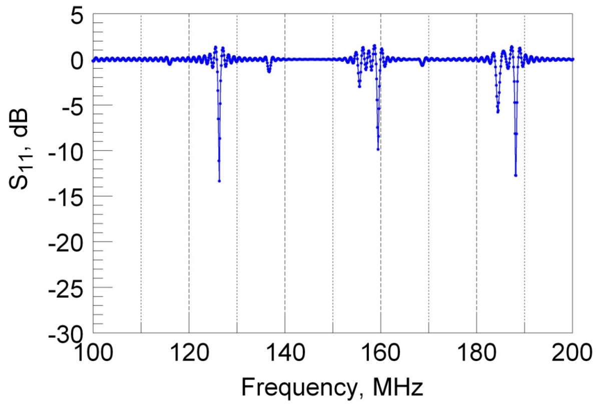

Figure 11.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = L/16.

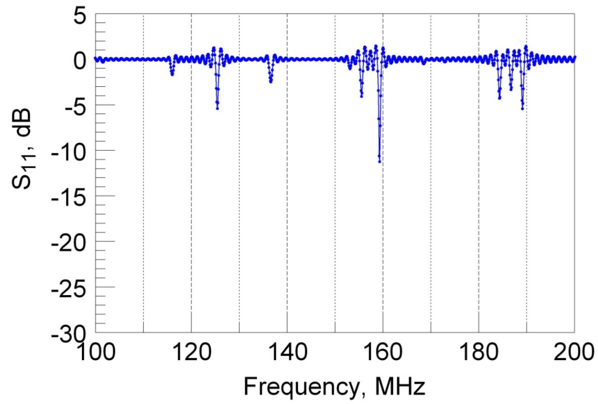

Figure 12.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = L/8.

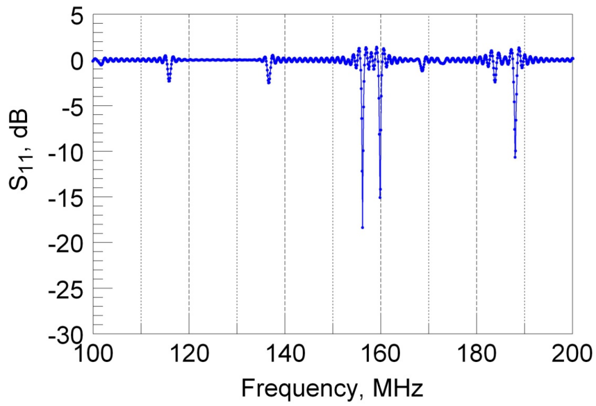

Figure 13.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = 3L/16.

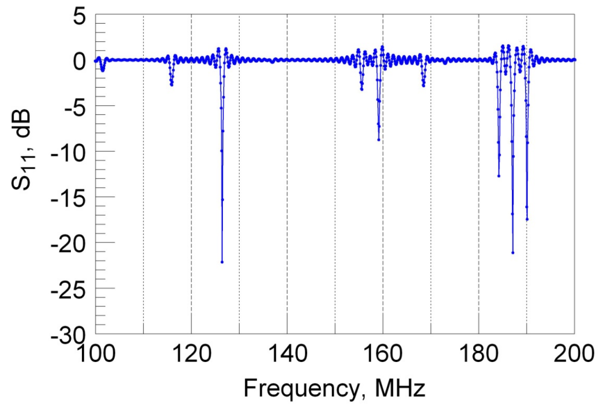

Figure 14.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = L/4.

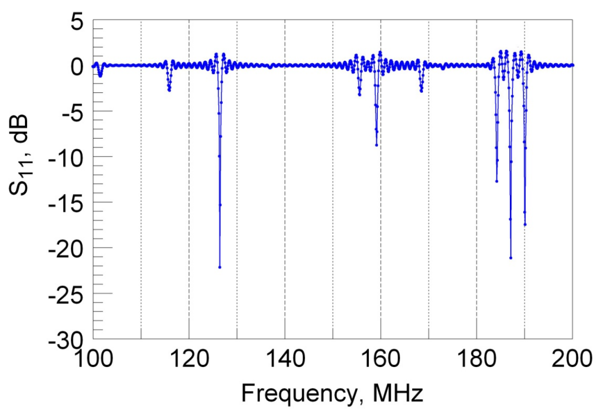

Figure 15.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = 5L/16.

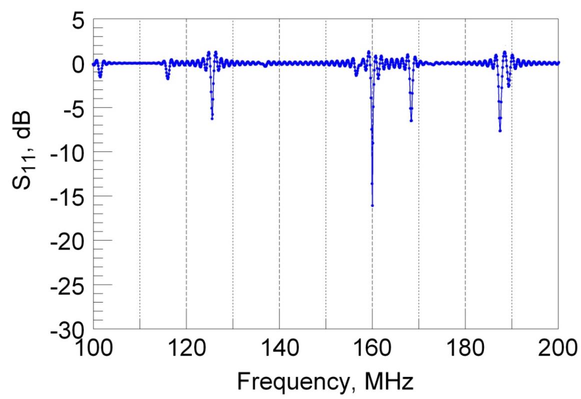

Figure 16.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = 3L/8.

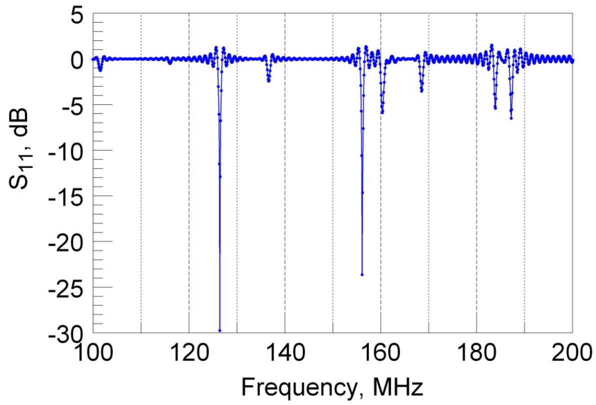

Figure 17.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = 7L/16.

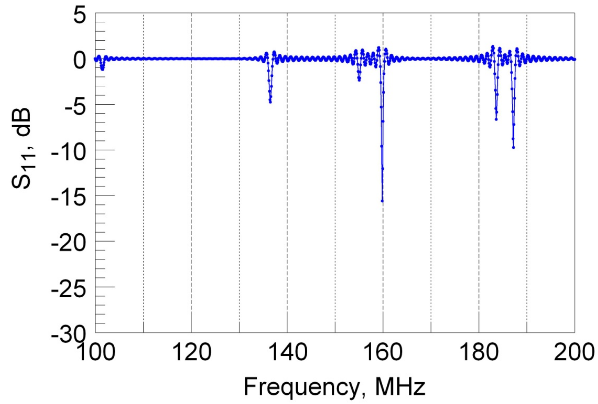

Figure 18.—Return loss with center-mounted configuration, monopole height = 25 cm, mounted at y = L/2.

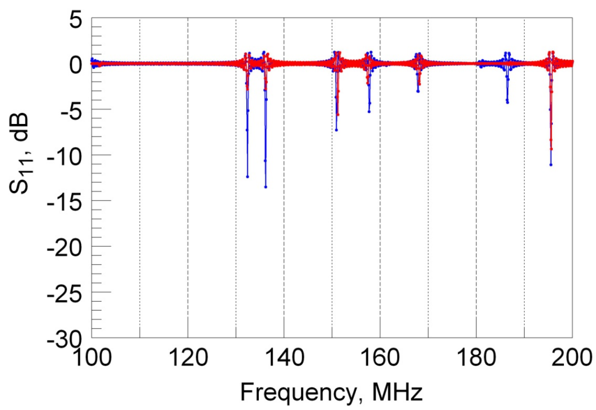

Figure 19.—Return loss with parallel (blue) and transverse (red) dipole antenna orientations.

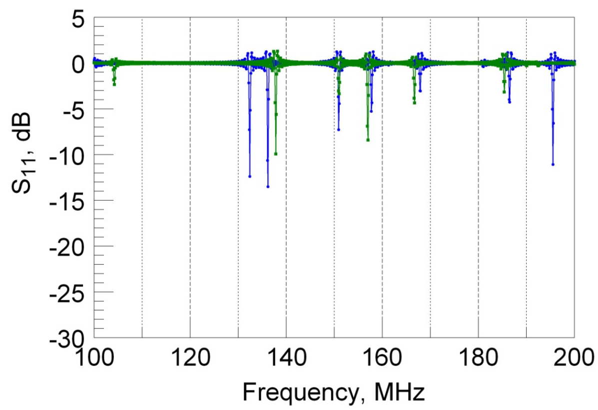

Figure 20.—Return loss for parallel dipole antenna with no baffles (blue) and three baffles (green).

Center-Mounted Dipole Antenna Configurations

The return losses for the transverse and parallel dipole configurations are compared in Figure 19. In general, there are significantly stronger responses predicted for the parallel orientation compared to the transverse orientation in this frequency range. The electric and magnetic fields for the eigenmodes excited by the parallel dipole antenna corresponding to frequencies 132.4, 136.1, 150.9, 157.7, 167.9, and 186.4 MHz are shown in Appendix C.

The effect of conducting baffle rings (slosh baffle plates) in the tank was also simulated. The baffles extended from an inner radius of 70.6 cm to the outer tank wall at a radius of 91.0 cm. The thickness in the y-direction is 0.3 cm. The top, center, and bottom locations are at 443.2, 236.5, and 29.8 cm from the bottom, respectively. The return loss is shown in Figure 20 for the parallel dipole configuration with and without baffles. Perhaps not surprisingly, the model predicts that the baffles change the amplitude of the response and also cause small shifts in frequency.

Conclusions

In this investigation, different monopole and dipole antenna mounting configurations and positions were modeled and responses simulated in a tank model with the transient solver of CST Microwave Studio over the frequency range 100 to 200 MHz. Three different mounting configurations were investigated for monopole antennas: top-mounted through the center of the tank lid, side-mounted on the side of the tank, and center-mounted on a central metal rod running from the top to the bottom of the tank. The simulations predict that mounting the antenna at the tank lid (top-mounted) will excite the transverse magnetic modes with moderate strength. Antennas mounted on the side of the tank are not predicted to strongly excite any modes in this frequency range, but this is contradictory to measurements which show a very good response. The center-mounted configuration in which the antenna was mounted on a central rod is predicted to be effective in exciting the lower frequency modes. Positioning the antenna at different locations along the central rod had a significant effect on the strength of excitation of the individual modes. A mounting height of 7/16 from the top was predicted to be especially effective. The responses of dipole antennas were modeled with both parallel and transverse mountings relative to a bar running along, but offset from, the long axis of the tank. The simulation results predict that a parallel mounting of the dipole is generally more effective at exciting the low frequency modes. The effects of baffles in the tank were also simulated. This had the effect of changing the amplitude of mode responses and slightly shifting the frequencies for several modes. Work is currently underway to experimentally test several of the configurations simulated here, and will be reported in a future publication.

Appendix A.—Sample Eigenmodes Excited by Top-Mounted Configuration

The electric field and magnetic field amplitudes of several eigenmodes for the top-mounted monopole antenna case are shown at a cross section of the tank:

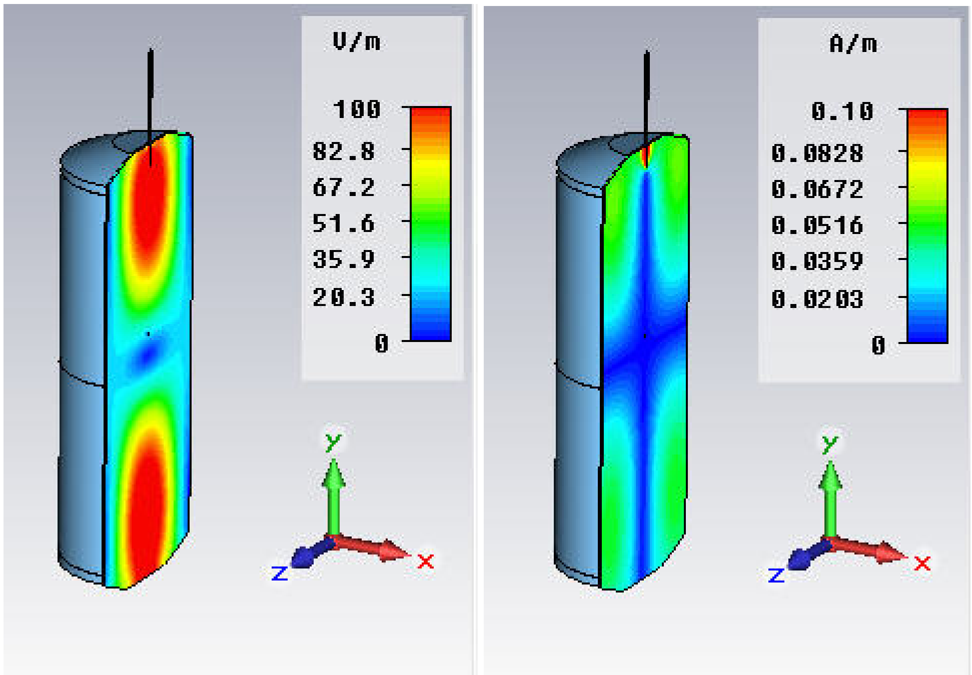

Figure A1.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 132.6 MHz for top-mounted monopole antenna.

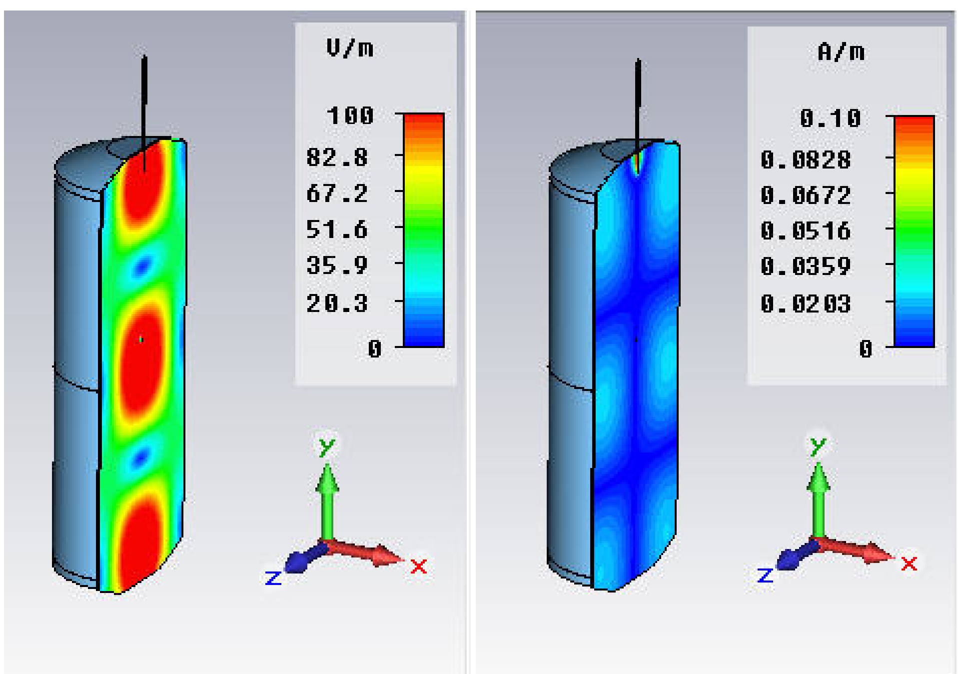

Figure A2.—Magnitude of (left) electric field and (right) magnetic field at cross section of the tank for eigenmode at 144.6 MHz for top-mounted monopole antenna.

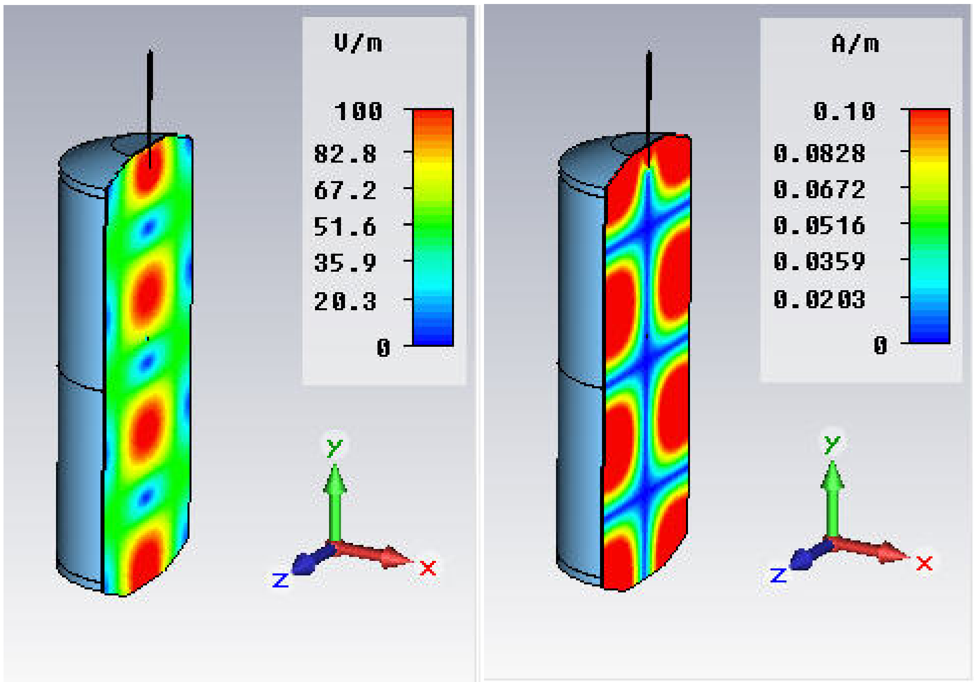

Figure A3.—Magnitude of (left) electric field and (right) magnetic field at cross section of the tank for eigenmode at 162.3 MHz for top-mounted monopole antenna.

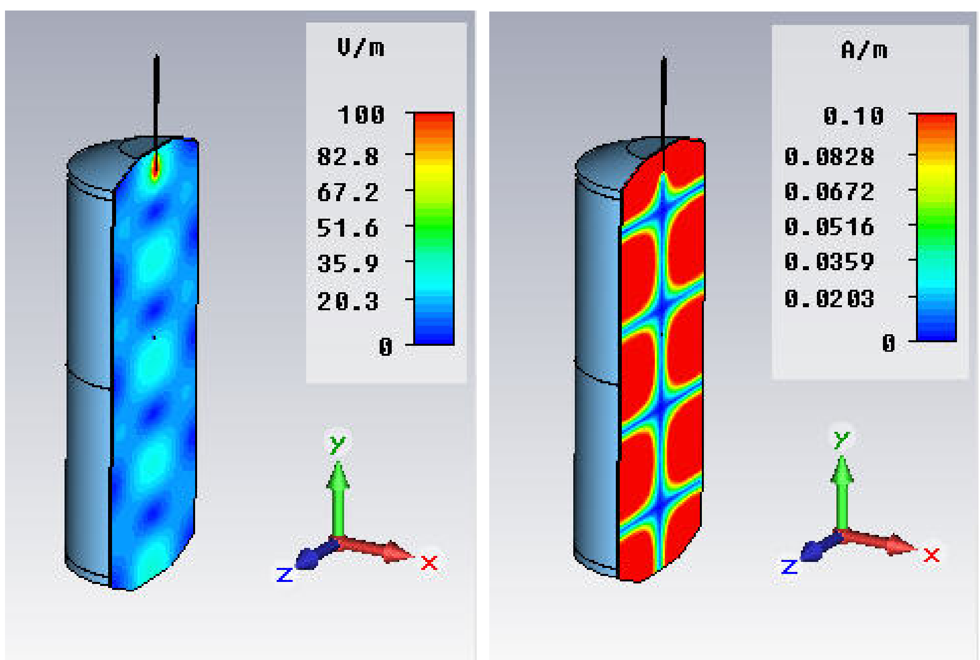

Figure A4.—Magnitude of (left) electric field and (right) magnetic field at cross section of the tank for eigenmode at 184.0 MHz for top-mounted monopole antenna.

Appendix B.—Sample Eigenmodes Excited by Center-Mounted Configuration

The electric field and magnetic field amplitudes of representative eigenmodes for the center-mounted antenna positioned 7/16 from the top are shown at a cross section of the tank. (The red arrow labeled "1" in each figure represents the antenna excitation port.)

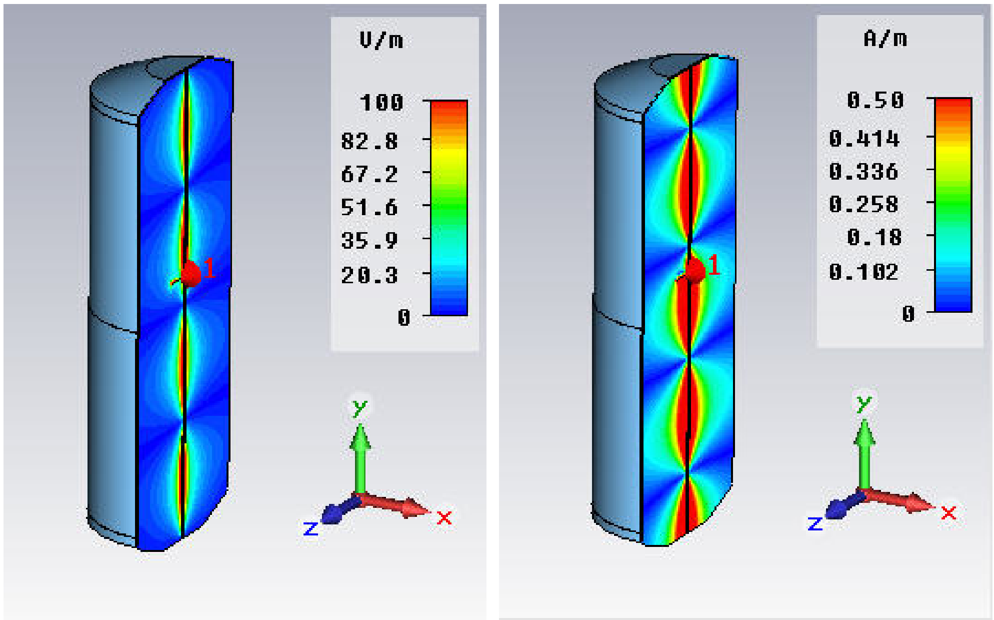

Figure B1.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 126.4 MHz for center mounted monopole mounted 7/16 from the top.

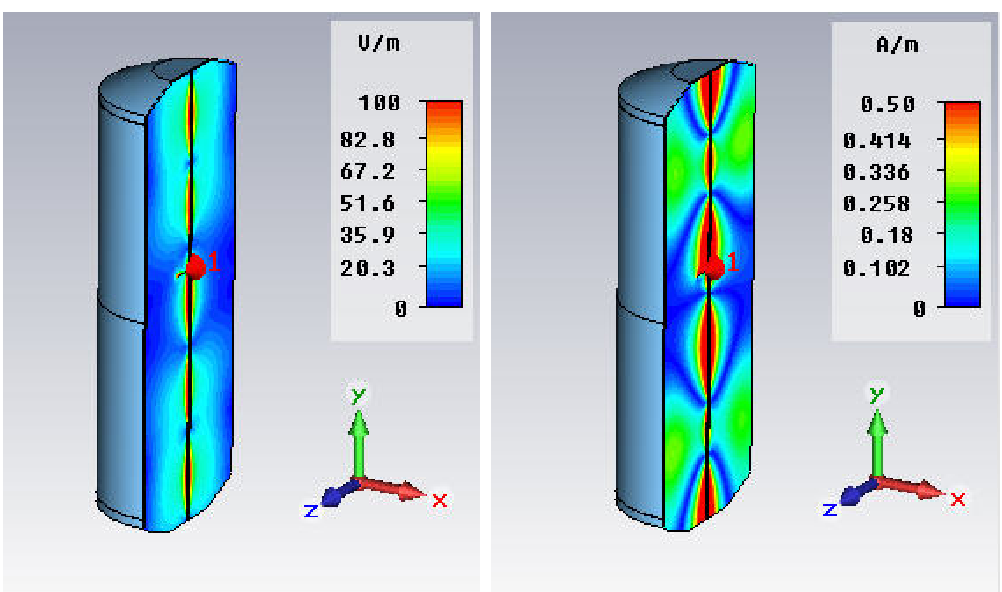

Figure B2.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 156.1 MHz for center mounted monopole mounted 7/16 from the top.

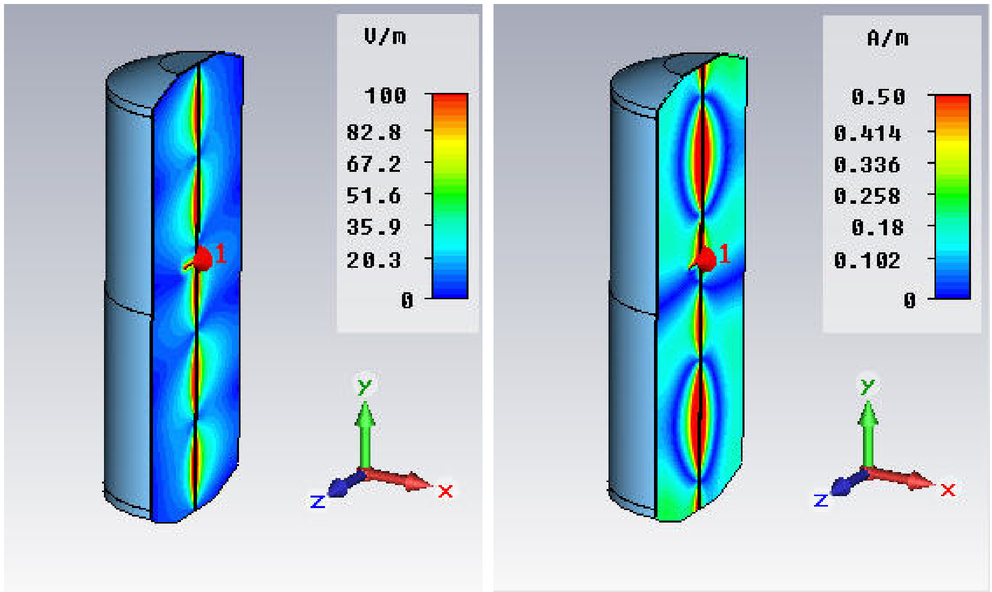

Figure B3.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 160.3 MHz for center mounted monopole mounted 7/16 from the top.

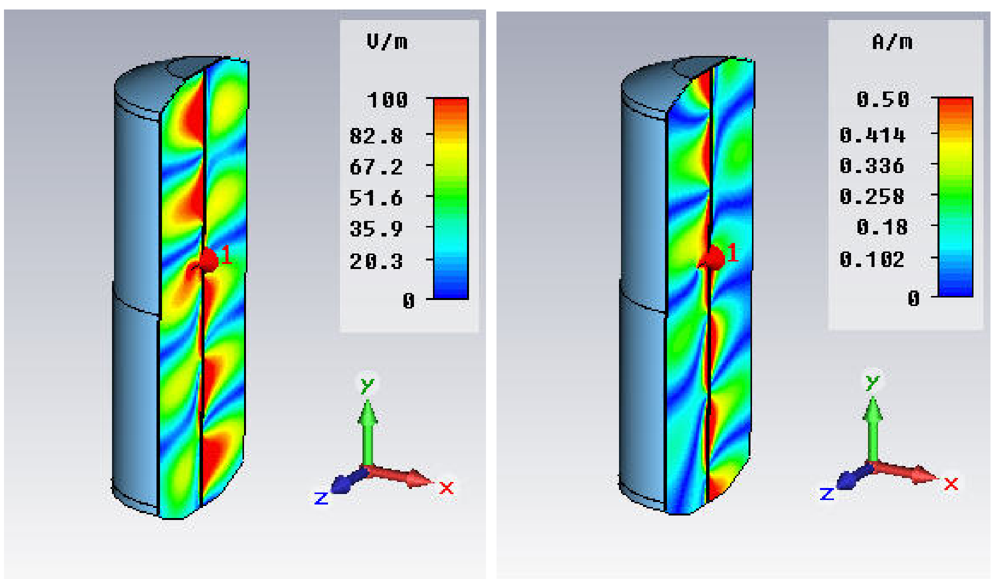

Figure B4.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 187.2 MHz for center mounted monopole mounted 7/16 from the top.

Appendix C.—Eigenmodes Excited by Parallel Dipole Orientation

The electric field and magnetic field amplitudes of several eigenmodes for the parallel dipole orientation are shown at a cross section of the tank:

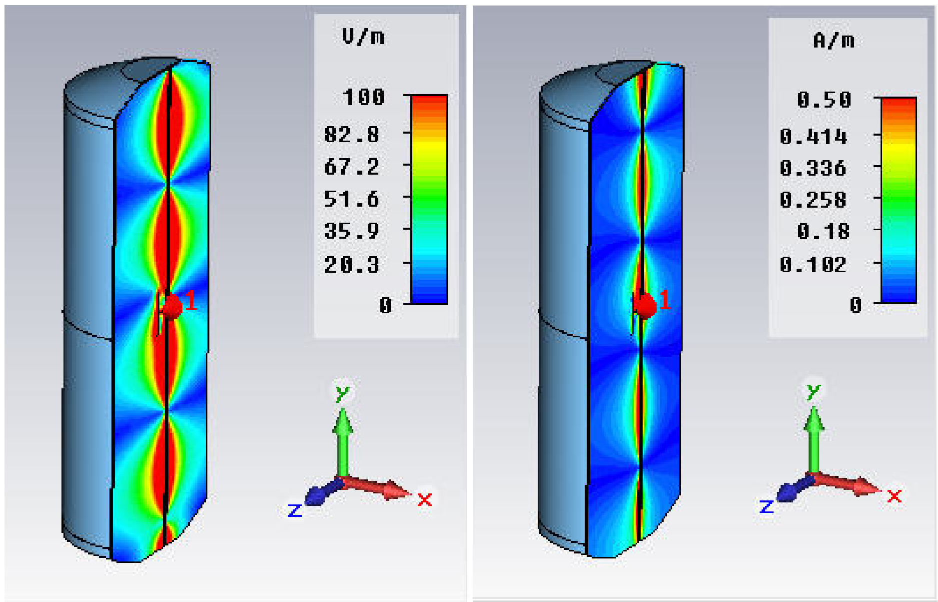

Figure C1.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 132.4 MHz for parallel dipole antenna orientation.

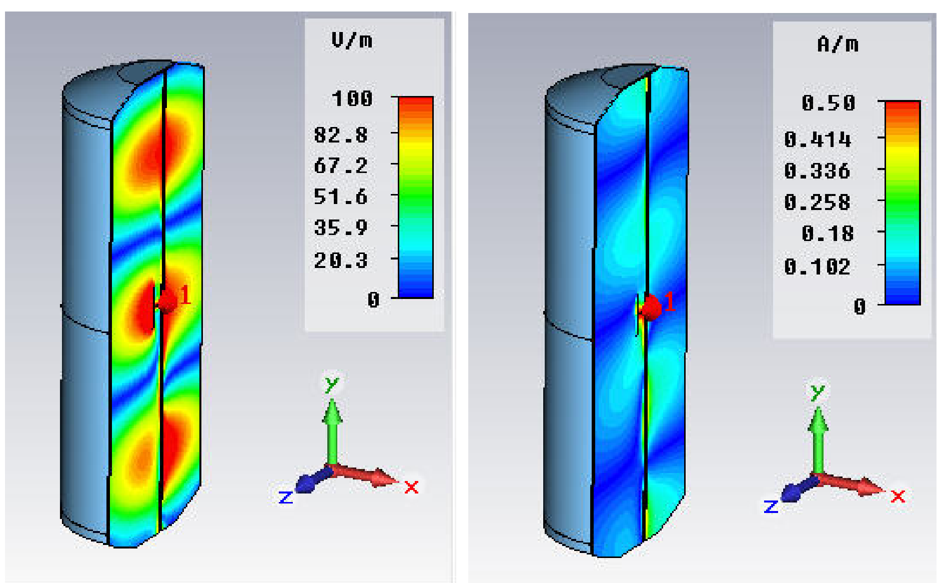

Figure C2.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 136.1 MHz for parallel dipole antenna orientation.

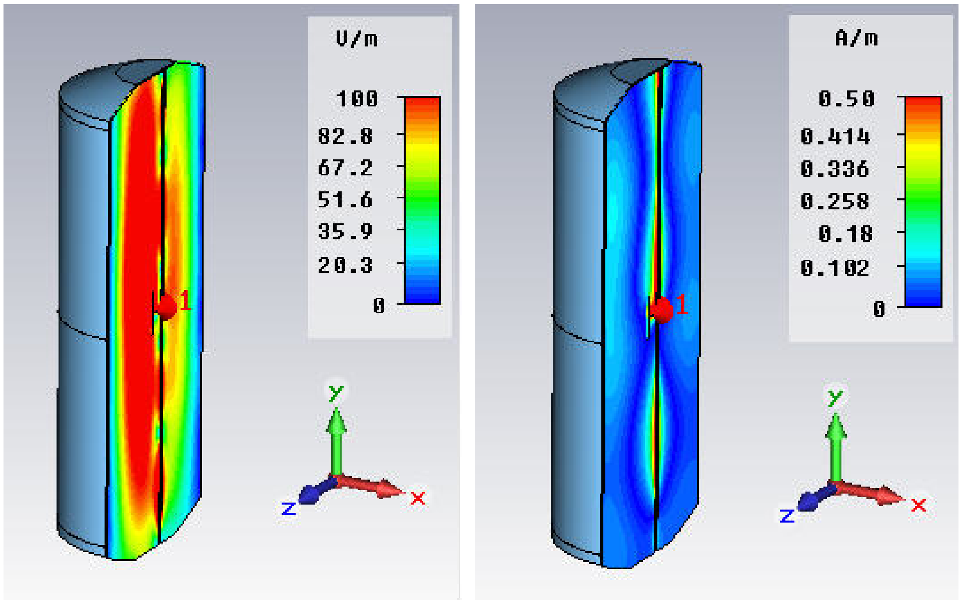

Figure C3.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 150.9 MHz for parallel dipole antenna orientation.

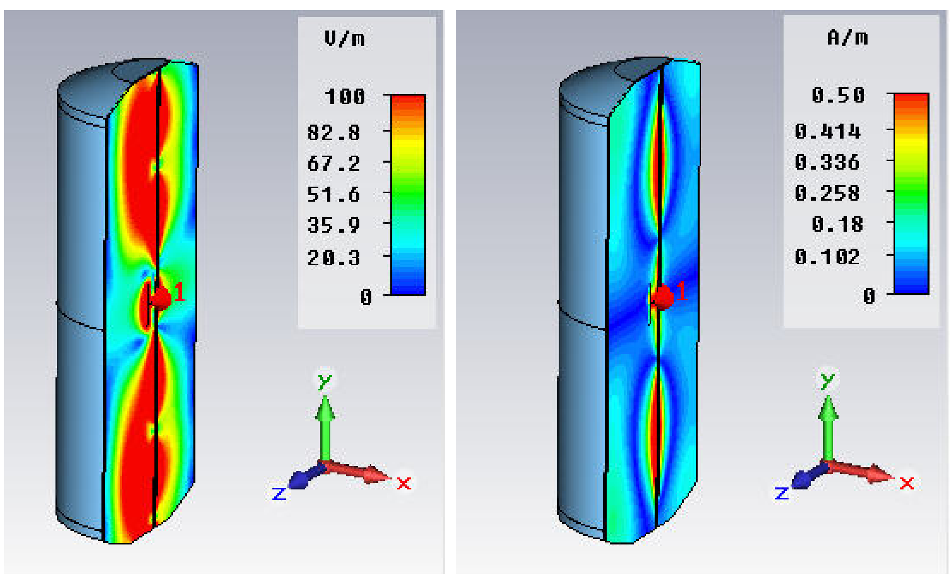

Figure C4.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 157.7 MHz for parallel dipole antenna orientation.

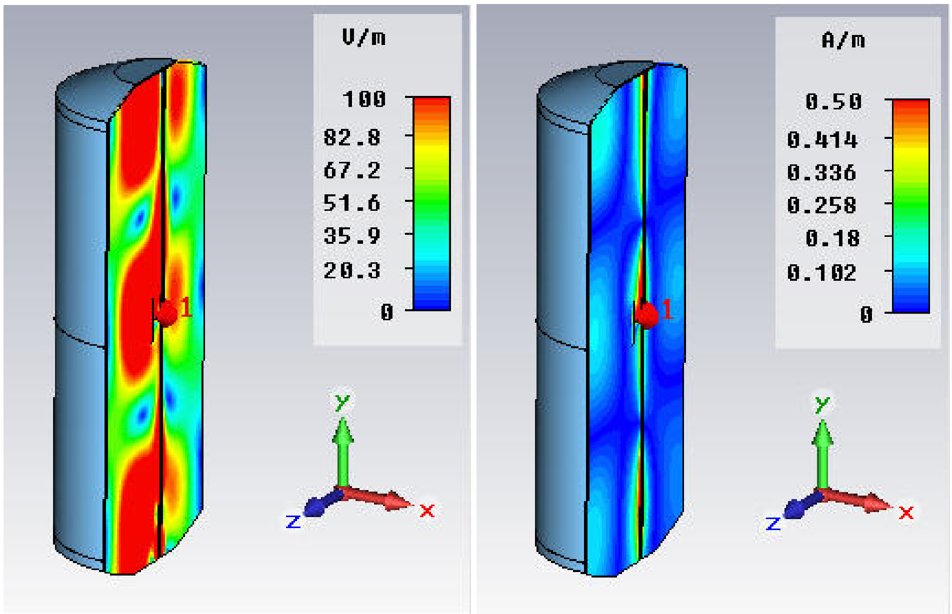

Figure C5.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 167.9 MHz for parallel dipole antenna orientation.

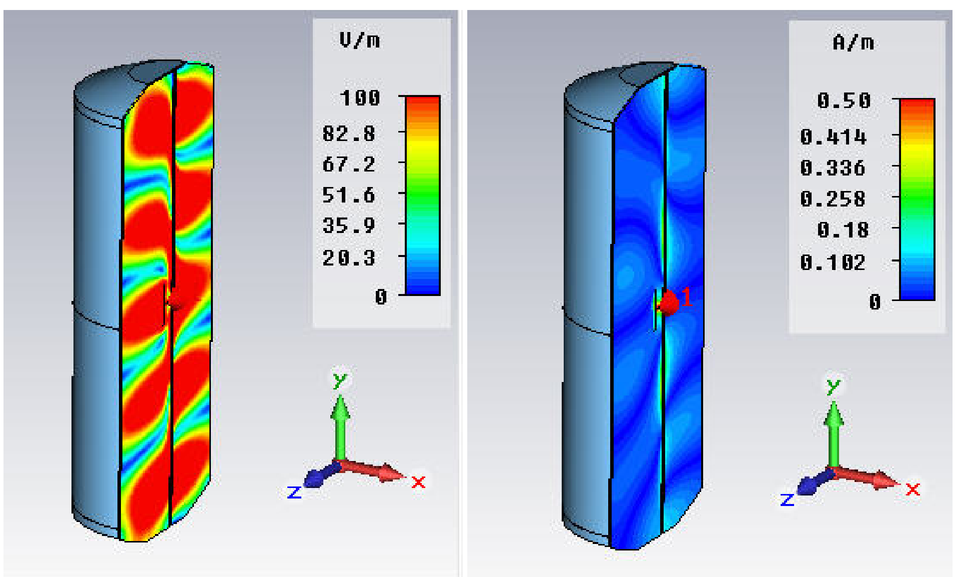

Figure C6.—Magnitude of electric field (left) and magnetic field (right) at cross section of the tank for eigenmode at 186.4 MHz for parallel dipole antenna orientation.

References

1. G.A. Zimmerli, M. Asipauskas, J.D. Wagner, and J.C. Follo, "Propellant Quantity Gauging Using the Radio Frequency Mass Gauge," 49th AIAA Aerospace Sciences Meeting, 4–7 January 2011, Orlando, Florida.
2. CST Microwave Studio Workflow & Solver Overview, Computer Simulation Technology AG, 1998–2010.

REPORT DOCUMENTATION PAGE						*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-01-2012

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Model of the Radio Frequency (RF) Excitation Response from Monopole and Dipole Antennas in a Large Scale Tank

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Wilson, Jeffrey, D.; Zimmerli, Gregory, A.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WBS 095240.04.03.04.01.03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-18022

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM-2012-217267

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category: 20
Available electronically at http://www.sti.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Good antenna-mode coupling is needed for determining the amount of propellant in a tank through the method of radio frequency mass gauging (RFMG). The antenna configuration and position in a tank are important factors in coupling the antenna to the natural electromagnetic modes. In this study, different monopole and dipole antenna mounting configurations and positions were modeled and responses simulated in a full-scale tank model with the transient solver of CST Microwave Studio (CST Computer Simulation Technology of America, Inc.). The study was undertaken to qualitatively understand the effect of antenna design and placement within a tank on the resulting radio frequency (RF) tank spectrum.

15. SUBJECT TERMS
Antenna design; Dipole antennas; Monopole antennas; Microwaves; Propellant tanks; Radio frequencies

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email:help@sti.nasa.gov)
U	U	U	UU	22	**19b. TELEPHONE NUMBER** *(include area code)* 443-757-5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18