NBSIR 73-346

RF TOTAL MASS GAUGING IN LARGE STORAGE CONTAINERS: EMPTY TANK MODES

R.S. Collier
Doyle Ellerbruch

Cryogenics Division
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Initial Report

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NATIONAL BUREAU OF STANDARDS, Richard W Roberts, Director

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ABSTRACT

This report describes experiments to determine the feasibility of radio frequency (RF) mass gauging for fluids stored in large containers. The experiments were done at the NASA Mississippi Test Facility using the 460,000 gallon LOX Storage Tank as an electromagnetic resonant cavity. The results show that the RF gauging technique is feasible for large containers.

Key Words: LOX storage container; radio frequency; total mass gauging

INTRODUCTION

The Radio Frequency (RF) mass gauging method uses the fluid container as a cavity which will contain electromagnetic waves. At certain frequencies (called resonant frequencies) the electromagnetic waves are stationary, forming resonant modes. At the resonant frequencies there is a good coupling between the RF antenna and the cavity which allows the resonant frequencies to be easily measured. As the container is filled with a dielectric fluid the resonant frequencies shift downward because the speed of wave propogation is decreased in the presence of the fluid. Hence, the possibility exists that the total mass of the fluid may be measured by measuring the change in the resonant frequencies.

Previous work [1] at the National Bureau of Standards on Radio Frequency (RF) Total Mass Gauging (contained in NBSIR 73-318) has shown the feasibility and accuracy of the RF method in small containers. Data have been obtained for hydrogen, nitrogen, oxygen and LNG in which a predictable change in the resonant frequencies have been observed with a change in mass.

We have proposed that the RF mass gauging technique be considered for large containers, in particular, for LNG shipboard and land storage containers as well as for fuel and oxidizer storage containers used in space flight.

The advantages of the RF technique are (1) the simplicity of the hardware involved and (2) the RF antenna senses the entire volume of the tank; this tends to have an integrative effect over all the fluid in the tank which approaches a true total mass gauge.

This report describes initial RF experiments on the 460,000 gallon LOX storage tank located at the NASA, Mississippi Test Facility. These experiments were done in cooperation with the NASA George C. Marshall Space Flight Center.

The purpose of the experiment was to see if a resonant response could be obtained from a large cavity tank and, if so, to answer the following questions:

(1) What are the frequencies of the resonant modes?

(2) Are the resonances sharp and well defined; i. e., what is the "Q" of the cavity?

(3) What is the coupling between the antenna and the container; what are the effects of antenna size?

(4) Is the technique feasible for total mass gauging in large containers?

It should be stated here that this work and also the work reported in NBSIR 73-318 is oriented toward spherical containers; this is because a sphere is a common container shape and also it is easier to study the modes of the sphere from a theoretical point of view. In principle, the technique could be extended to an arbitrary shaped container. Questions on container shape must be answered as the need arises; in particular large containers could be scale modeled in the laboratory if the scaling laws between large and small containers were well understood; this report will show that further work needs to be done in this area, particularly in establishing values for the resonant frequencies of large containers.

Also, if RF gauging is to be applied to LNG, it will be necessary to understand the relationship between the dielectric constant and the density (or effective heating value) of LNG mixtures. It is possible that the RF technique may have an integrative effect over the constituents of the mixture. Also, it is anticipated that the RF antenna will not be adversely affected by heavy hydrocarbon contamination as experienced on capacitive type probes.

OPERATIONAL PROCEDURES

The external views of the sphere are shown in Figures 1 and 2. The sphere is stainless steel; the inner diameter is 49 feet and there is 5 feet of insulation between the inner sphere and the outer sphere. The sphere is part of the LOX supply system at the NASA Mississippi Test Facility. At the time of the experiment the sphere was at ambient temperature and had been purged with dry air.

Access to the inner part of the sphere is obtained through double manhole covers on the inner and outer sphere is shown in Figures 3 and 4. A positive purge was maintained on the vessel to help maintain the LOX compatibility of the inner sphere.

The RF antenna was mounted on a 1/4-inch aluminum plate as shown in figure 5. This plate replaced the inner manhole cover shown in Figure 4 and just rested without bolting on the inner manhole rim. Two different types of antenna were used: the u-shaped antenna shown in Figure 5 was 18 inches x 18 inches, had one side grounded to the aluminum plate and the other side led through an insulated feed-through to a coaxial connector; also, a whip-type telescoping (dipole) antenna was used, this was, in fact, an automobile radio antenna of adjustable length.

The electronic equipment as shown in Figure 6 consisted of a 10 milliwatt RF generator which could be hand tuned or swept in frequency on a linear ramp between two fixed frequency values. The RF signal is fed on coaxial cable through a directional coupler to the antenna; the reflected signal is fed back from the same antenna through the directional coupler to the oscilloscope. Most of the data was taken on the platform on top of the sphere; some data was taken at the bottom of the sphere with a 120 foot coaxial cable from the antenna; a van was provided, as shown in Figure 1, for taking data in inclement weather but was never used.

Figure 1. LOX storage tank.

Figure 2. LOX tank stair access.

Figure 3. LOX tank outer manhole access.

Figure 4. LOX tank inner manhole cover.

Figure 5. RF loop antenna.

Figure 6. Electronic equipment

Figure 7 shows a LOX compatible entry into the inner container in which visual observation indicated that the inner geometry was truly a sphere with only three minor tubular intrusions into the tank. This was born out by the data which showed no splitting of the spherical degeneracy of the modes.

Figure 7. LOX compatible tank entry.

EXPERIMENTAL DATA

The initial data was taken with the dipole antenna extended to its full length of 54 inches. After some initial adjustments the RF generator was set to sweep on a linear ramp between 20 MHz and 50 MHz. Figure 8 shows the signal at the scope; the horizontal scale is frequency 20-50 MHz, left to right, and the vertical scale is the signal amplitude as reflected back through the directional coupler.

Figure 8(a) is the signal reflected back from the end of the open coaxial line; that is, the antenna was not connected. The wavy response is characteristic of the 20 foot coaxial line representing standing waves set up in the line.

Figure 8(b) is the same signal with the antenna connected; the absorption lines of the first seven TM modes of the cavity are seen to be superimposed on the general background response.

Figure 9 shows the effect of inserting a crystal detector between the directional coupler and the scope; the wavy response is filtered out and the absorption lines become spikes at the detector output. These spikes can then be used to trigger digital timing circuits to convert the frequency measurements to the time domain as described in NBSIR 73-318.[1] The important feature of the spike is that the leading edge (left hand edge) of the spike is very steep; this contributes to precise timing measurements and greatly enhances the accuracy of the technique as a mass gauge.

The sweep on the RF generator was turned off and the generator was hand tuned to each of the spikes in succession and the frequencies were read directly with a counter. The frequencies of the first seven TM modes were as follows:

Figure 8(a). Signal reflected from an open coaxial line 20 feet long.
Horizontal scale 20 - 50 MHz.
Vertical scale 0. 1 volt/cm.

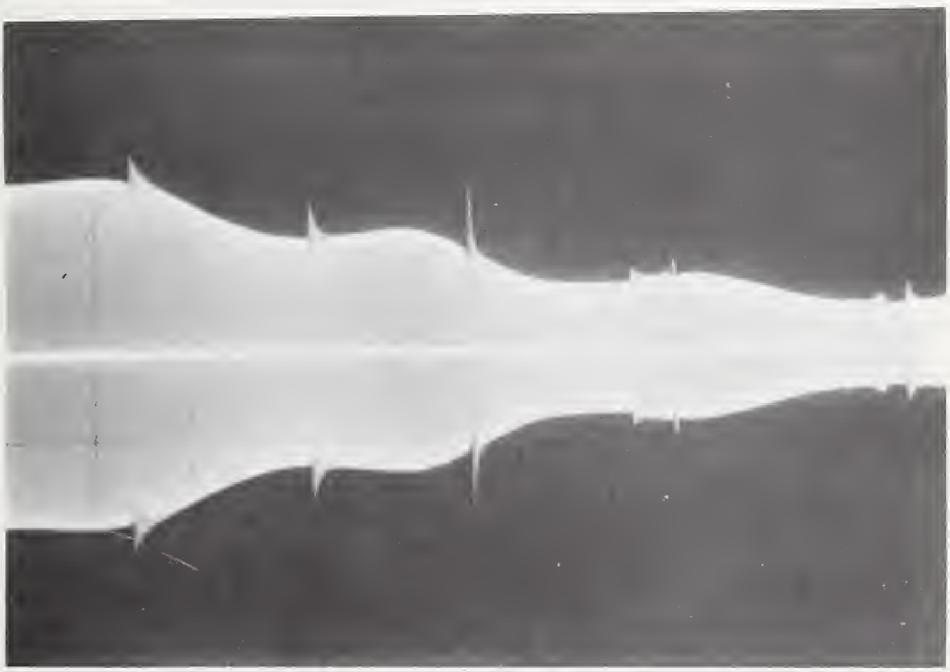

Figure 8(b). Same signal with the whip antenna connected.

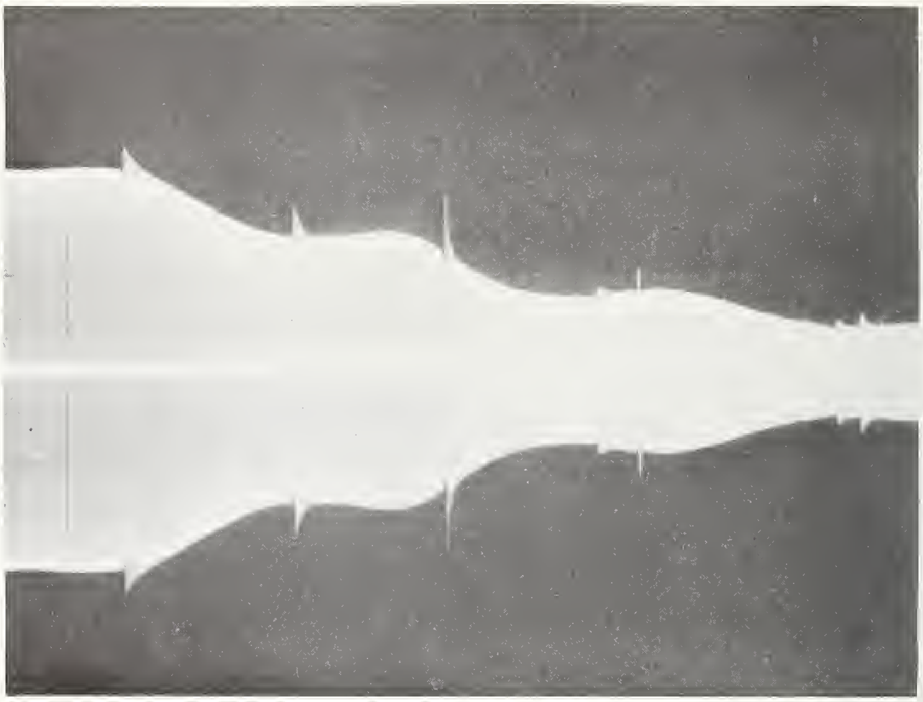

Figure 9(a). Signal from the whip antenna.
Horizontal scale 20 - 50 MHz.
Vertical scale 0. 1 volt/cm.

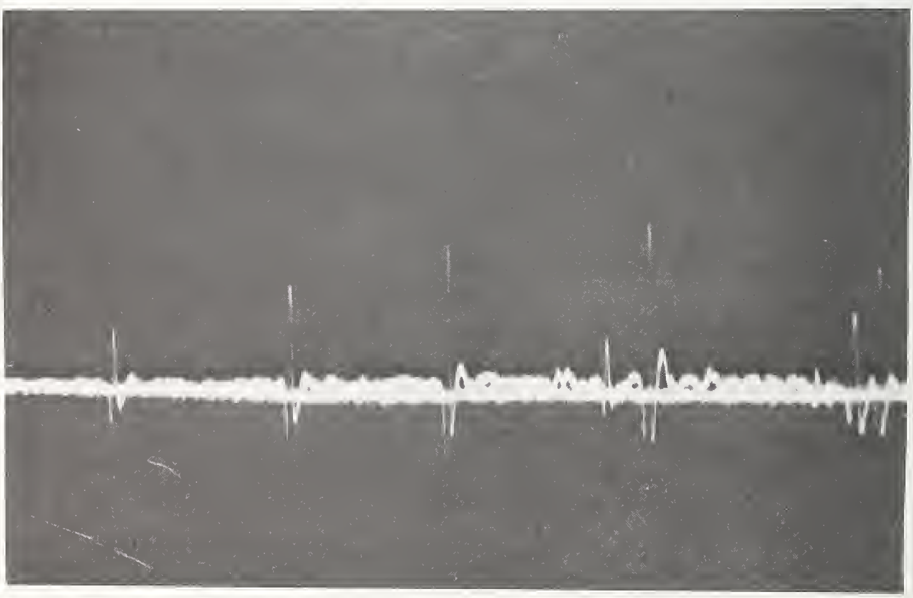

Figure 9(b). Same signal as seen by a crystal detector.

Mode	Frequency (MHz)
TM_{011}	24.09
TM_{021}	29.36
TM_{031}	34.19
TM_{041}	39.07
TM_{012}	40.38
TM_{051}	46.80
TM_{022}	47.59

These measurements were repeatable to ± .02 MHz. In addition to these data, the loop antenna picked up an additional mode; the TE_{011} at 31.62 MHz.

Figure 10 shows the effect of a remote measurement taken at the end of a 120 foot coaxial line leading to the bottom of the sphere. Figure 10(a) shows the open circuit response; the wavy nature of the response has changed due to the increase in line length. The cavity response is shown in figure 10(b) and a crystal detector gives the same spike pattern as shown in Figure 9(b).

Figure 11 shows an expanded scale of the absorption line and the spike for the TM_{011} mode. The full scale sweep is about 1 MHz; from this, it is estimated that the width of the line at the half power point is on the order of 0.01 MHz. This is roughly the accuracy of the frequency measurement. The Q of the cavity is this width divided by the center frequency giving a lower limit on Q of approximately 2000. This is very encouraging from an accurate gauging point of view. Figure 12 gives the same conclusion for the TM_{021} mode.

Figures 13 and 14 give a qualitative picture of the effect of antenna size on the coupling to the cavity. Figure 13(a) is the response from a

25 inch long dipole antenna; the absorption lines are barely detectable. In Figure 13(b), the antenna is 31 inches long; 14(a), 37 inches long; 14(b), 49 inches long. From this study, it appears that the antenna size should be roughly 1/20 the diameter of the cavity. This is consistent with the previous work on 18 the inch diameter cavity where the antenna size is on the order of one inch.

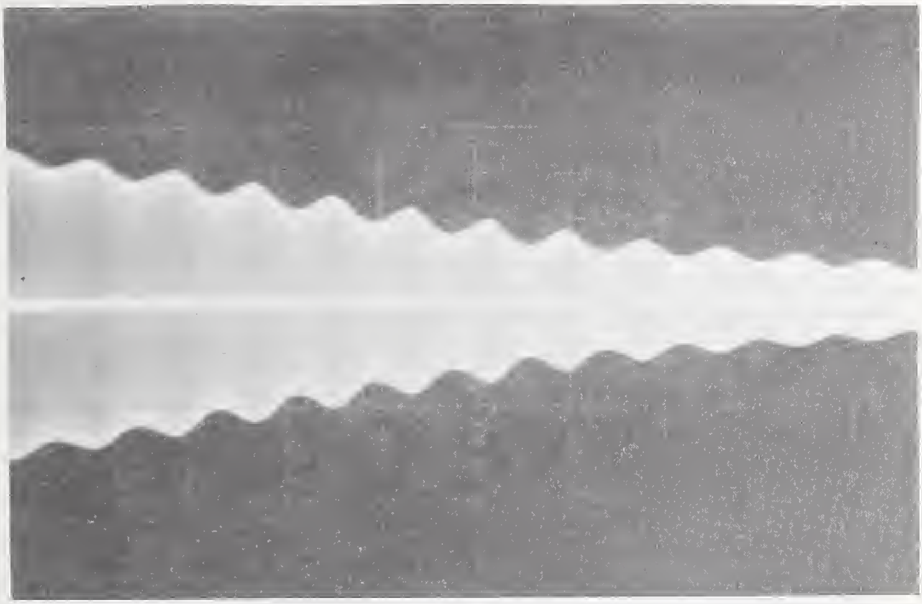

Figure 10(a). Signal from an open coaxial cable 100 feet long.
Horizontal scale 20 - 50 MHz.
Vertical scale 0. 1 volt/cm.

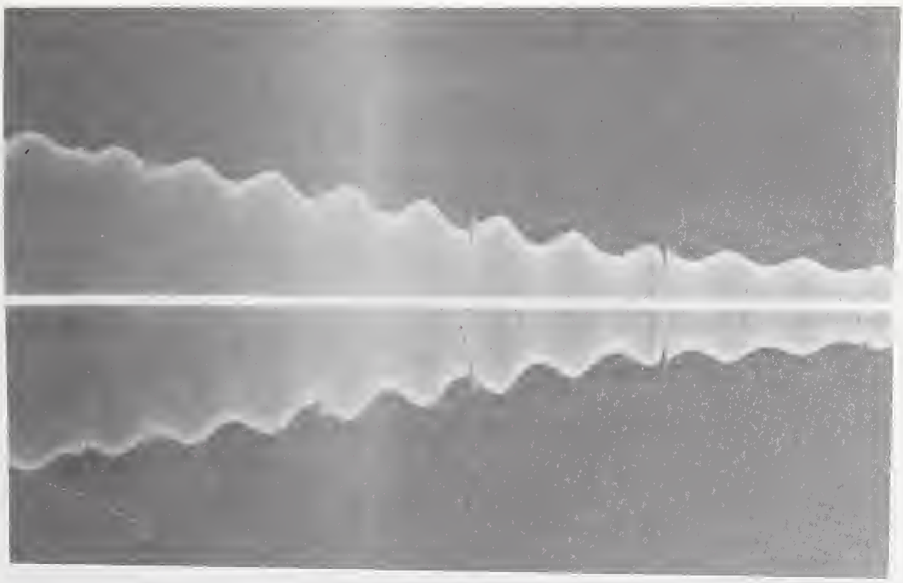

Figure 10(b). Same signal with the whip antenna connected.

Figure 11(a). Expanded view of signal centered on the first mode.
Horizontal scale
1 MHz full scale
Pulse frequency 24.09 MHz
Vertical scale 0.1 volt/cm

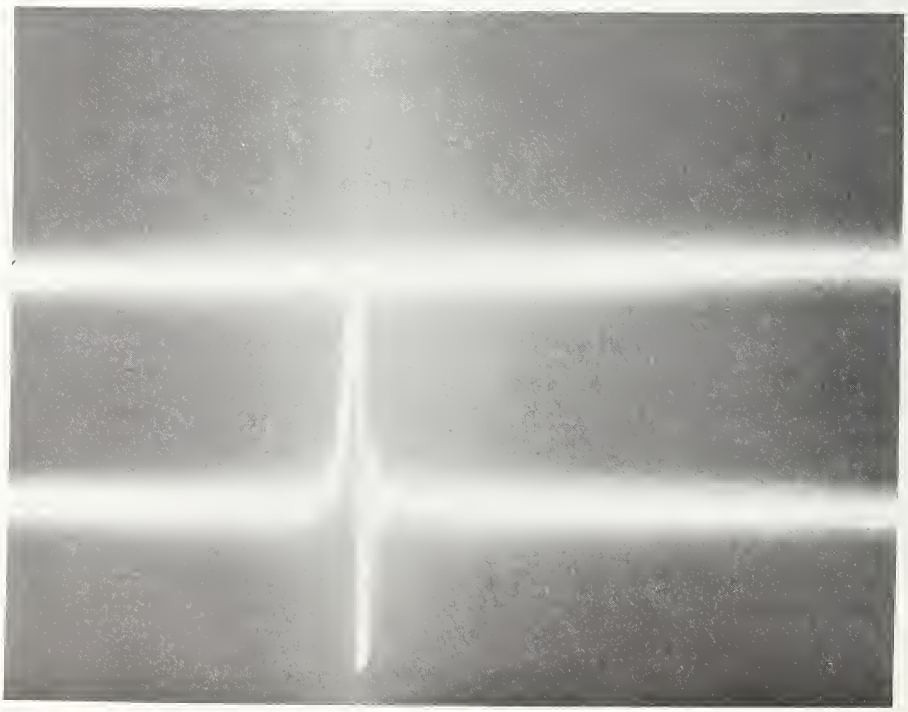

Figure 11(b). Same signal as seen by a crystal detector.

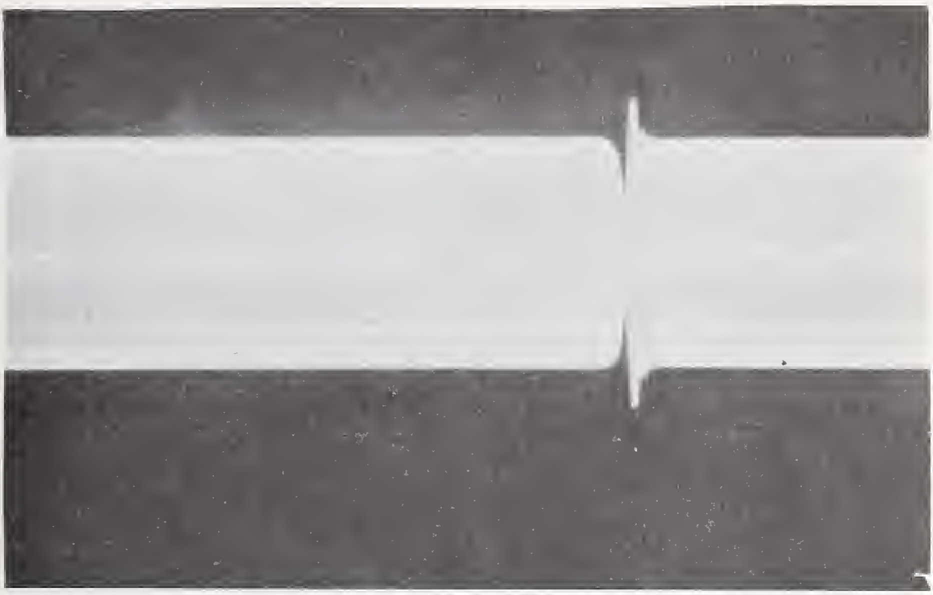

Figure 12(a). Expanded view of the signal centered on the second mode.
Horizontal scale.
1 MHz full scale.
Line frequency 29. 36 MHz.
Vertical scale 0. 1 volt/cm.

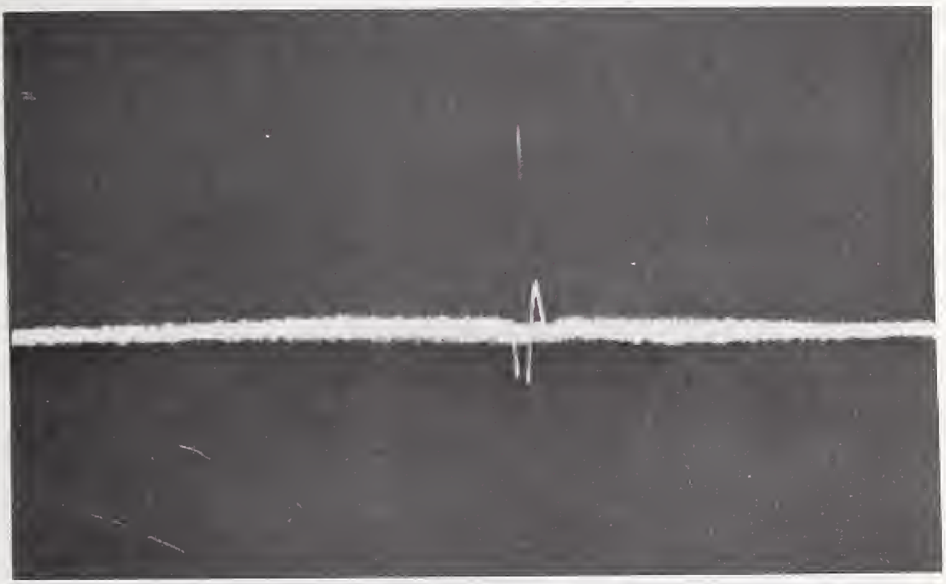

Figure 12(b). Same signal as seen by the crystal detector.

Figure 13(a). Signal from the whip antenna extended 25 inches.
Horizontal scale 20 - 50 MHz.
Vertical scale 0.1 volt/cm.

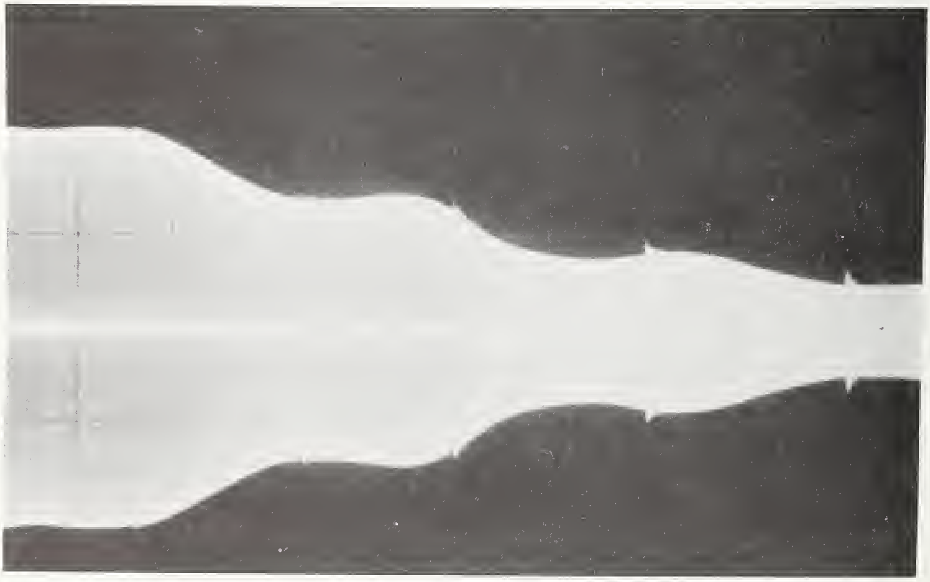

Figure 13(b). Signal from the whip antenna extended 31 inches.

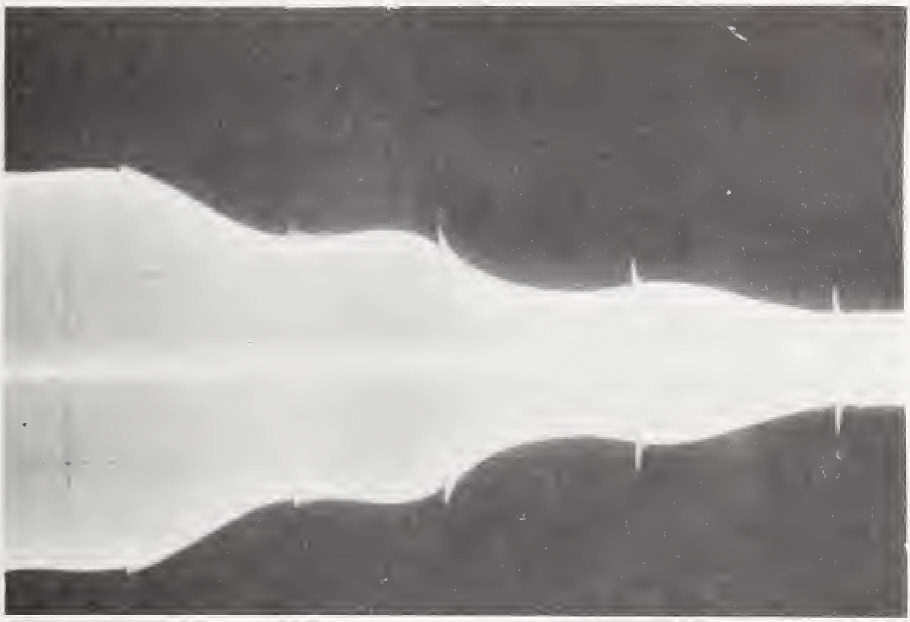

Figure 14(a). Signal from the whip antenna extended 37 inches.
Horizontal scale 20 - 50 MHz.
Vertical scale 0. 1 volt/cm.

Figure 14(b). Signal from the whip antenna extended 49 inches.

CONCLUSIONS

These experiments show that it is possible to excite the resonant modes of a large tank; that the response is sharp and well defined; and hence, the RF technique is a feasible method for large tank total mass gauging. The frequencies of the modes were somewhat higher than expected; the differences between the experimental and theoretical values for the resonant frequencies are as follows:

Mode	$(freq)_{exp} - (freq)_{calc}$ MHz
TM_{011}	6.59
TM_{021}	4.70
TM_{031}	2.49
TM_{041}	0.47
TM_{012}	1.38
TM_{051}	2.77
TM_{022}	0.19

It is seen that the agreement becomes better for the high frequency modes. This difference produces no conceptual problems to the mass gauging process. However, if large tanks are to be modeled in the laboratory, this effect needs to be more clearly understood. The calculated frequencies were obtained assuming perfect cavity walls; it is possible that at the lower frequencies, the wall permeability losses become important to the calculations. This point should be investigated.

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17. KEY WORDS (Alphabetical order, separated by semicolons)

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