N72-24320

SUMMARY REPORT

RF QUANTITY GAUGING SYSTEM

CR-115584

Contract No. NAS9-12450

Prepared for:

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SUMMARY REPORT ON RF QUANTITY GAUGING SYSTEM MODIFICATIONS FOR CONTRACT NAS9-12450

This report summarizes the work done on the RF Quantity Gauging System, Contract No. NAS9-12450. The contract objectives were to modify, calibrate, and test the RF liquid mass gauging system, Bendix Type X1625027, for optimum performance in gauging the RP-1 furnished by NASA MSC. The following paragraphs summarize the current system configuration, testing methods, and test results. Also included is a discussion of those results and their ramifications for further investigative work areas.

System Electronics Modifications

The electronic processing section of the system was modified to reflect the latest mode processor design and to incorporate AC-line filtering which should permit operation with electrical supply systems containing relatively high levels of spurious electrical noise. The old mode processing circuit was removed and replaced with a newer printed circuit board version. This newer mode processor and the original ramp generator, power leveler, and pulse-to-analog converter boards were physically mounted in a new chassis box which in turn was mounted within the original electronics housing (cover). This was done to provide more thorough electrical isolation from the system power supplies. The AC-line filtering was placed in a small separate metallic utility box which was secured to the overall electronics housing. The RF section of the system was not changed, since it was found that changing the RF oscillator would not have changed the overall slope of the RF gauging response.

Theoretical Loading Response

The math model that has been formulated to predict the loading response of the RF gauging system is given by:

$$N_o(\alpha) = \frac{Q_L}{2\beta}\left\{\exp\left[-\frac{2\beta K(\alpha) f_1^{\,3}}{Q_L}\right] - \exp\left[-\frac{2\beta k(\alpha) f_2^{\,3}}{Q_L}\right]\right\}$$

where: $K(\alpha) = \frac{8\pi V}{3C^3}[1 + (\varepsilon' - 1)\alpha]^{1.5}$

V = Volume of the tank

ε' = real part of the complex dielectric constant

f - the excitation frequency

c = the speed of light

α = mass fractional fill

Q_L = the loaded Quality factor of system

β = mode merging parameter

When supplied to the systems spherical aluminum test tank with RP-1 as the test fluid, the predicted RF gauging loading response for an RF frequency band of 1.875 - 3.0 GHz results in a descending loading response as shown in Figure 1, where the number of detectable resonant modes decreases with increasing amounts of dielectric. For this particular set of input parameters with the tank and for RP-1, this operating frequency band turns out to be just about optimum in terms of the overall slope of the gauging response. By shifting this frequency band slightly lower in the frequency spectrum, the sensitivity or slope of the loading response is improved by only a small amount as illustrated by the loading response for 1.5 - 3.0 GHz which is also seen in Figure 1.

Experimental Results

The system was subjected to a series of tests designed to establish the best operating frequency range. These tests revealed that the 1.875 - 3.0 GHz frequency band covered by the RF oscillator in the system electronics was adequate. These results substantiated the predictions provided by use of the RF Gauging Math Model. Testing with the 1.5 - 3.0 GHz RF oscillator which was borrowed from the Air Force (Contract F33657-70-C-0053) for use on the contract resulted in only a very small improvement in gauging performance, in terms of high end sensitivity of the loading response. As a consequence, the 1.875 - 3.0 GHz RF oscillator was retained for use in the system.

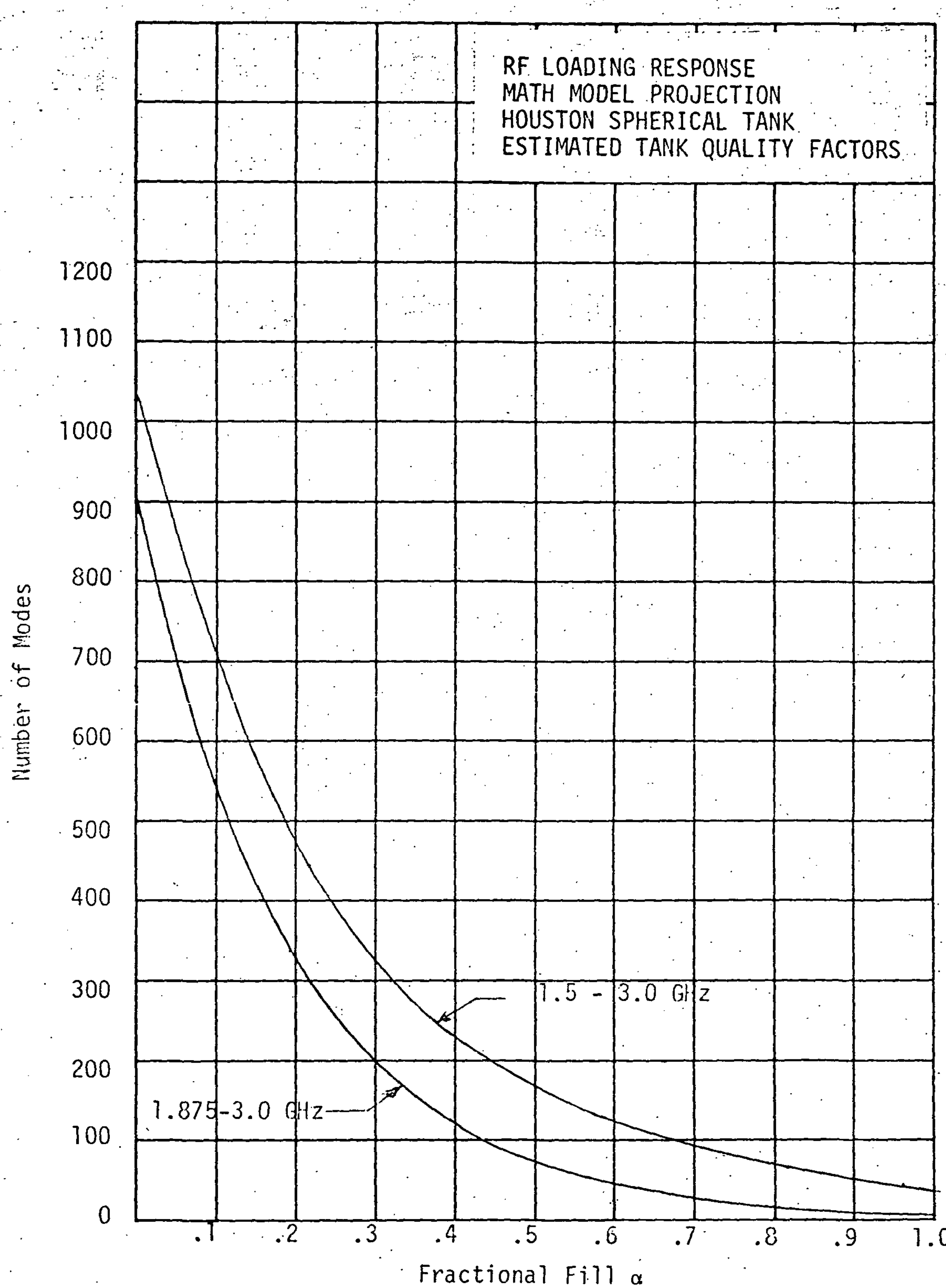
RF LOADING RESPONSE
MATH MODEL PROJECTION
HOUSTON SPHERICAL TANK
ESTIMATED TANK QUALITY FACTORS
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Number of Modes
1.5 - 3.0 GHz
1.875-3.0 GHz
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Fractional Fill α

Figure 1

Further evaluations of the detected resonant mode pattern obtained with the empty test tank revealed that the distribution of modes within the operating frequency band was not very uniform, but somewhat clustered into groupings. To break up these groupings of modes, several aluminum rods were tack welded in various random positions within the tank to break up the perfect symmetrical nature of the tank. A much more uniform distribution of the detected resonant mode solutions was immediately evident and hence the rods were left in the tank.

To permit evaluation of the system performance under a normal one 'G' gravity environment, loading response tests were then performed with the tank positioned in its assembly cart gimbal. This gimbal permits the tank to be orientated to various angular positions relative to gravity. Loading response tests performed under such various tank positions provide a simple means by which to simulate Zero 'G' conditions; i.e., by orientating the tank to various relative to the fluid-air interface of the test dielectric. To permit a more detailed evaluation of the RF gauging response, a capacitance bridge controller was connected to a capacitance probe which was placed in the barrel reservoir containing the RP-1, and its analog output was used to drive one input of an X-Y recorder, while the analog output of the RF gauging system was used to drive the other input of the X-Y recorder. This setup provides a continuous recording of the RF system analog output versus mass of RP-1 Previous setups required that the RF gauging system output (generally mode count) be recorded for discrete increments of mass as determined by weighing the contents of the RP-1 remaining in the barrel reservoir. Figure 2 shows the loading response obtained with RP-1 in the spherical tank for four angular positions of the tank where for each angular position the tank was pressurized to facilitate emptying. This process of emptying the tank was done slowly and in such a amnner as to induce little or no sloshing of the RP-1 in the test tank. In effect, the only motion within the tank during the withdrawal of RP-1 for each tank position was the steady motion of the receding RP-1 air interface. Figure 3 shows the

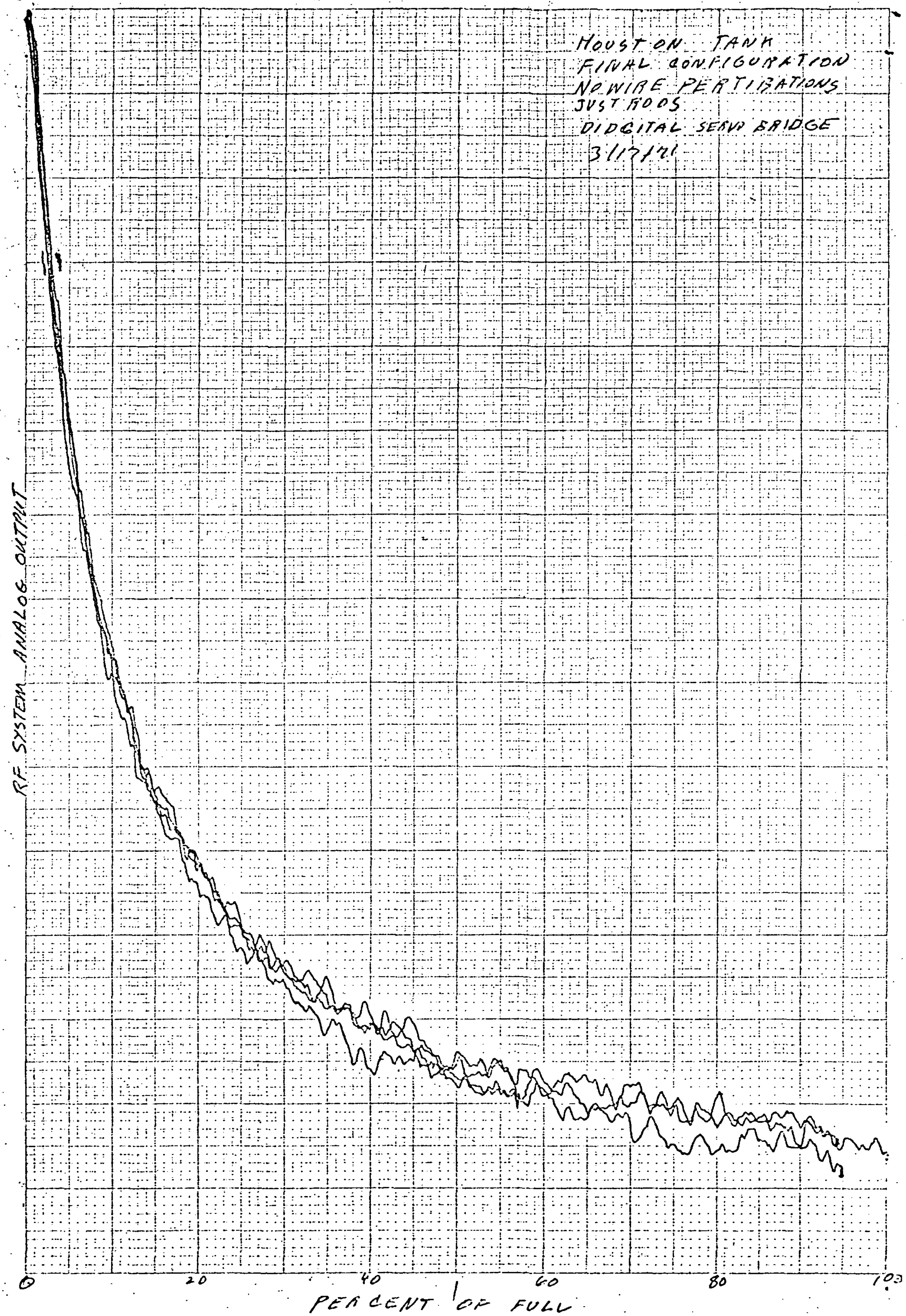
HOUSTON TANK
FINAL CONFIGURATION
NO WIRE PERTIBATIONS
JUST RODS
DIDGITAL SERVO BRIDGE
3/17/71
RF SYSTEM ANALOG OUTPUT
0
20
40
60
80
100
PERCENT OF FULL

Figure 2

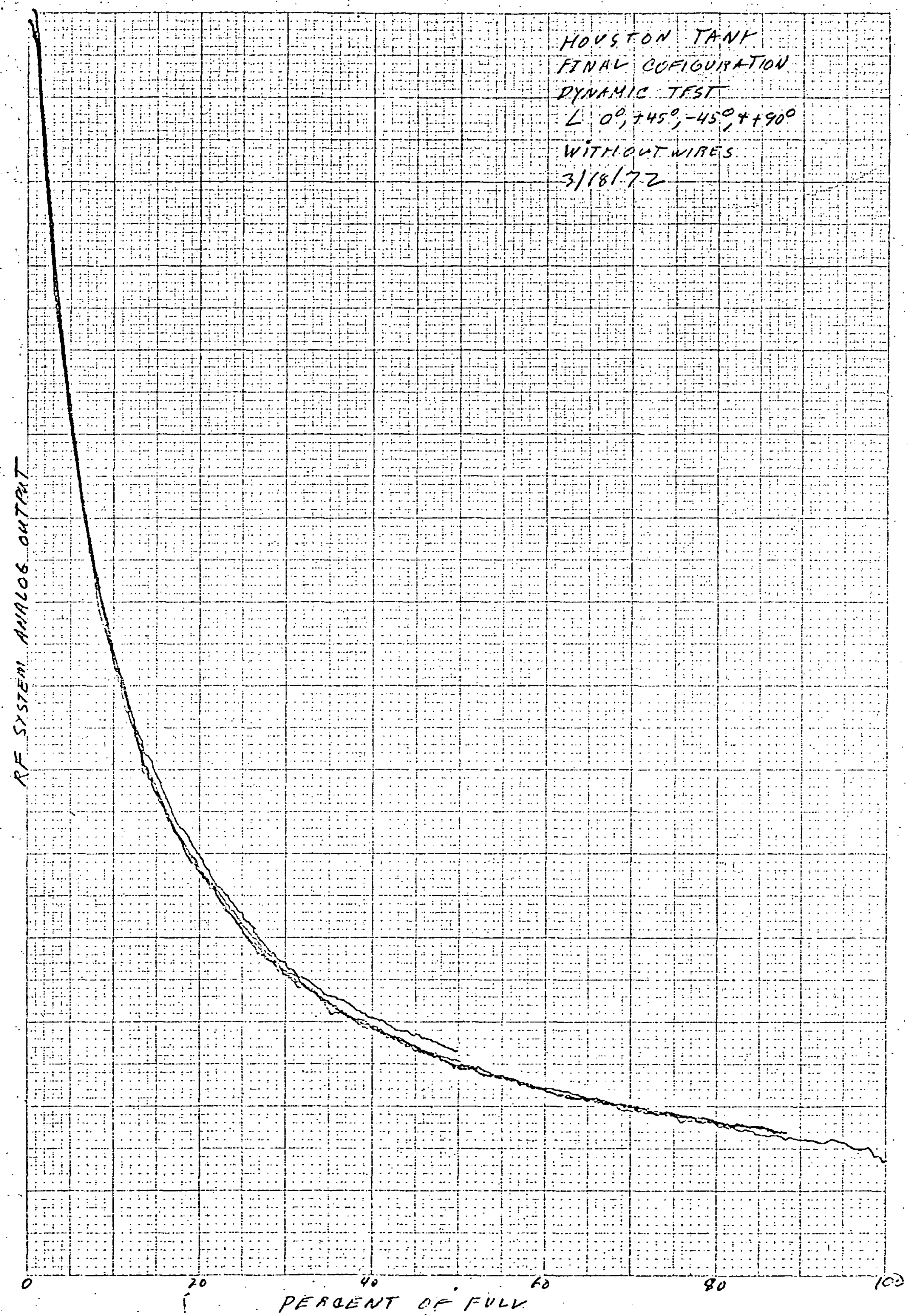
HOUSTON TANK
FINAL COFIGURATION
DYNAMIC TEST
∠ 0°, +45°, -45°, + +90°
WITHOUT WIRES
3/18/72
RF SYSTEM ANALOG OUTPUT
0
20
40
60
80
100
PERCENT OF FULL

Figure 3

loading response obtained for the same liquid and angular positions of the tank; however, the RF electromagnetic fields within the tank were, in this case, forced to vacillate in such a manner as to permit a more optimum overall coupling to the resonant mode solutions. Physically this was accomplished by inducing the RP-1 to slosh gently within the tank. Similar results have been achieved by using a small bladed fan or stirrer in the tank in such a manner as to vacillate the electromagnetic fields. Bubbling gas through the test liquid, or recycling a small quantity of RP-1 by means of an air-driven pump which removed RP-1 from one location in the tank and forced it back in the tank at another location in the form of a pulsating spray produces the same favorable effect. In each of these cases where the electromagnetic fields within the tank are forced to fluctuate in some prescribed manner, the gauging error (the variation in the RF gauging output for given mass quantities) was reduced significantly as typically indicated by Figure 3. In effect, a better sampling or average of the interaction of the electromagnetic fields and the RP-1 mass was obtained. The same effects should be obtainable by electronically vacillating the electromagnetic fields within the tank.

The tank was then opened and several lengths of copper wire were fastened mechanically to several points within the tank. This was done to determine if additional internal perturbations would enhance the gauging results. Figure 4 shows the loading response obtained with RP-1 with the tank in this configuration for the same four angular postions of the tank where, as in Figure 2, the only motion within the tank during the withdrawal of RP-1 for each tank position was the steady motion of the receding RP-1 - air interface. When compared to the results in Figure 2, it is clear that the overall system performance for these 'non-dynamic' situations was significantly improved by the addition of the copper wires. With the copper wire remaining in the tank, the test was repeated under conditions where the RF electromagnetic fields within the tank were, once again, forced to vacillate by inducing the RP-1 to slosh gently within the tank. The results in this case are shown in Figure 5. Once again the system performance is greatly enhanced when the electromagnetic fields within the tank are forced to vacillate. Note, however, that there is very

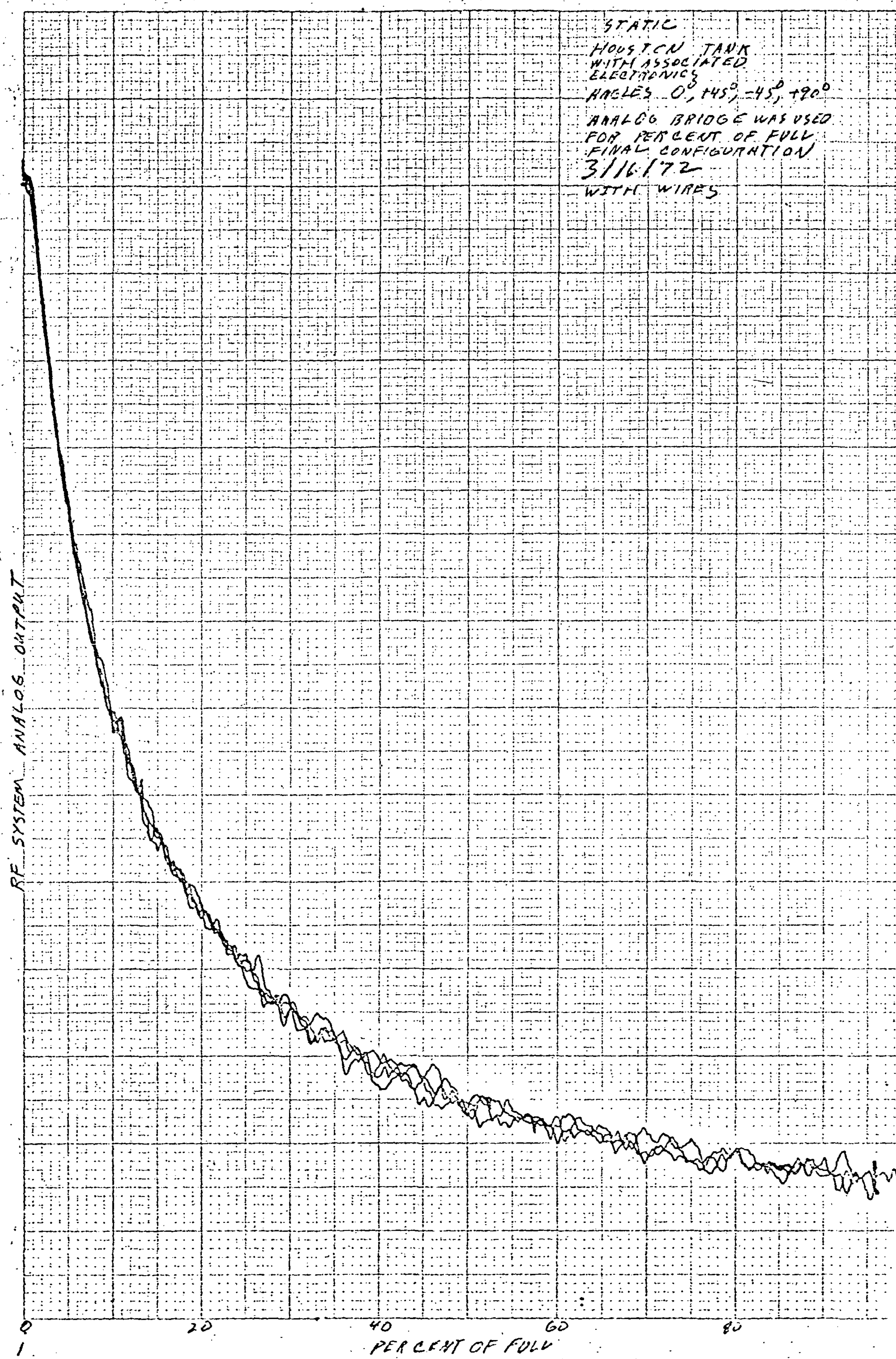
STATIC
HOUSTON TANK
WITH ASSOCIATED ELECTRONICS
ANGLES 0°, +45°, -45°, +90°
ANALOG BRIDGE WAS USED FOR PERCENT OF FULL
FINAL CONFIGURATION
3/16/72
WITH WIRES
RF SYSTEM ANALOG OUTPUT
0
20
40
60
80
1
PERCENT OF FULL

Figure 4

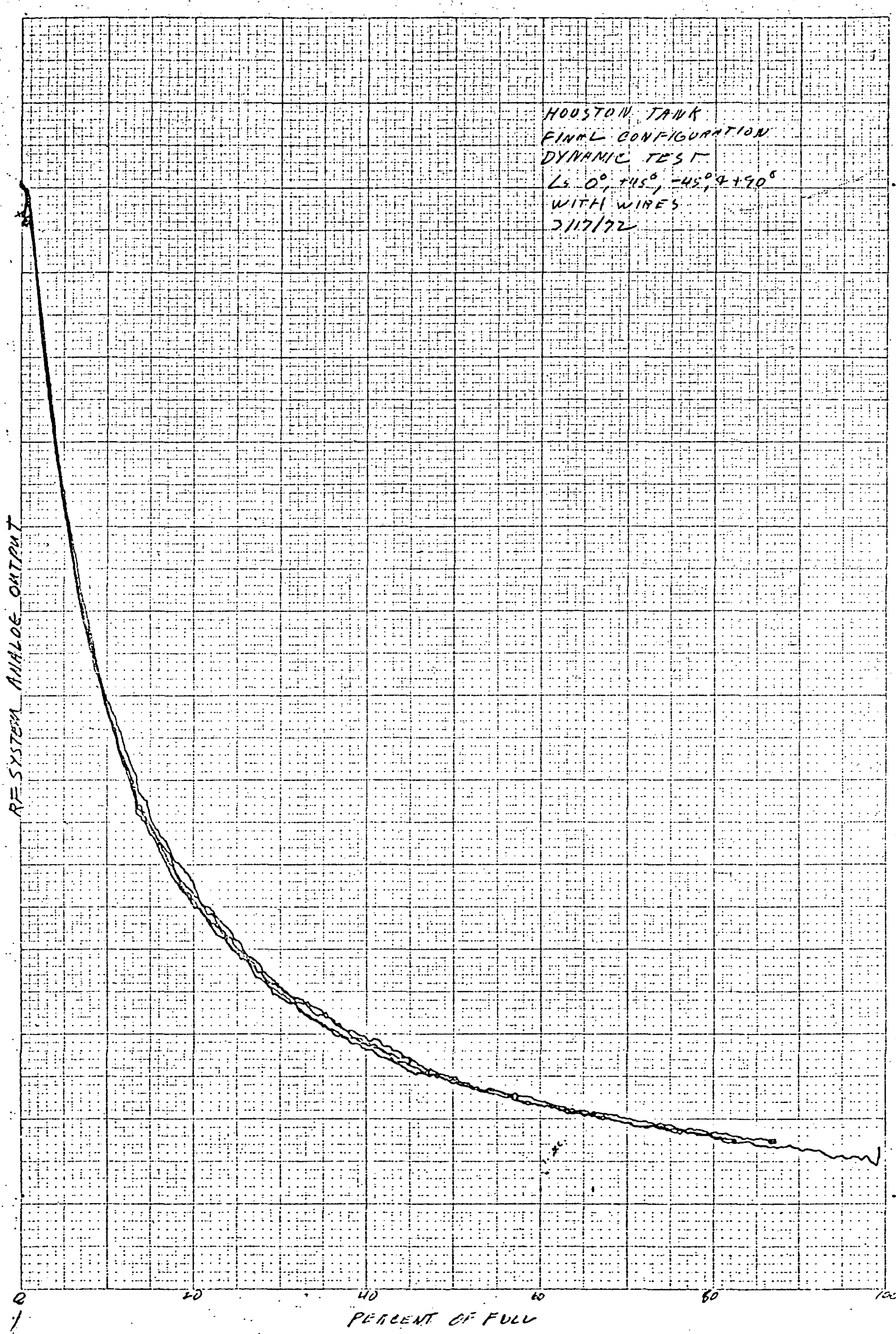
HOUSTON TANK
FINAL CONFIGURATION
DYNAMIC TEST
∠s 0°, +45°, -45°, + +90°
WITH WIRES
2/17/72
RF SYSTEM ANALOG OUTPUT
0
20
40
60
80
100
PERCENT OF FULL

Figure 5

little difference in the results obtained in Figures 3 and 5.

The mechanism behind the phenomena which permits a more accurate determination of mass can best be understood by considering the situation that exists within the tank for a given mass of dielectric. When this dielectric is fixed in the tank at one specific position, and the tank interior is illuminated with RF energy, a definite set of electromagnetic fields are spacially established in the tank. The field configurations are characterized by distinctive electromagnetic resonances that exist only at specific frequencies. The number of these resonances that can be detected within a selected RF frequency band is called the resonant count.

The RF antenna is basically a transformer whose function is to couple RF energy between the external RF energy source and the interior of the tank. Its coupling to the electromagnetic fields established within the tank in part determines the characteristic system Q, and consequently contributes to the number of modes that are detected. When the dielectric assumes an arbitrary second fixed position by orientation of the test tank, the spacial positioning of the electromagnetic fields within the tank are apparently perturbed slightly. As a result, the antenna coupling factors associated with the resonant modes must be similarly altered by some small amount. Since this change in coupling factor for each mode is a function of the spacial variation of the electromagnetic fields, it follows that it is also related to the respective wavelengths of those modes. These changes in coupling factors appear to modify the overall system Q, and therefore change the detected resonant mode count. This phenomena appears to account for at least part of the variation in mode count that is seen for various tank orientations with a typical given mass of dielectric, and hence contributes to the overall performance of the gauging system in terms of mass errror as depicted in Figures 2 and 4. The improvements in this data as shown in Figures 3 and 5, as stated earlier, were brought about when the electromagnetic fields within the tank were induced to vacillate by some means so that they were displaced by finite distances. By forcing these fields to vacillate continuously, the probe coupling factors relating to each respective resonant mode were varied in accordance with that displacement.

The detected mode counts at each mass level were subsequently forced to vary between maximum and minimum values which were in turn averaged over several of the RF sweep periods. This averaging was brought about by the inherent electronic circuitry delays in the pulse-to-analog converter portion of the system electronics.

The above phenomena with its potential for providing better system mass accuracies has been demonstrated by mechanically forcing the electromagnetic fields to vacillate. It soon becomes apparent that it would be most desirable to find an electronic means by which to accomplish the spacial movements in these electromagnetic fields. This requirement could in all probability be implemented by several techniques. Since the mode averaging is induced by the apparent physical displacement of the electromagnetic fields relative to the RF antenna position, the same effect could be achieved by the use of a RF probe assembly containing two or more fixed antenna elements displaced physically from one another by dimensionally less than one-quarter wavelength of the average of middle frequency of the operating frequency band. By the use of a solid-state pin diode type single-pole multi-throw switch the RF energy source would be programmed to sweep f_1 to f_2 sequentially through each antenna element. Using three antenna elements in a single RF probe assembly would mean that the RF energy source would sweep from f_1 to f_2 in 20 ms (typical) using the first antenna element, then using the second antenna element, and finally the third antenna element for a total of 60 ms per sampling period. The mode counts detected for each of the three respective sweeps could easily be summed and averaged electronically. A secondary, and closely related advantage of this multi-element concept is that the physical presence of two or more antenna elements clustered at various angles on the RF probe assembly would assure that the polarization of each antenna element would in effect permit a more distributed coupling to the established electromagnetic fields, and at the same time enhance a more uniform RF illumination of the tank than can now be achieved with a single antenna element.

Another possible way that the electromagnetic fields within the tank could be induced to vacillate electronically would be to vary the apparent electrical length of the RF antenna element by switching into the RF antenna line several various electrical line lengths in a psuedo random sequence. The switching would be programmed to occur at the end of each sweep of the RF oscillator. The resonant mode counts detected during each sweep would be totaled and averaged electronically for each of the psuedo random switching sequences.

Impact on RF Gauging Technique

Relative to the above data and technical discussion it is clear that the described phenomena should be further investigated for possible implementation in a RF gauging system. The electronic approach to force a better sampling of the electromagnetic field-mass interaction as put forth in the above discussion appears feasible and would greatly enhance both the accuracy and versatility of the RF gauging technique to liquid mass measurements.