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Report 2497

Research with the Waveguide
Beyond Cutoff or Separated
Aperture Dielectric Anomaly
Detection Scheme

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 This report presents experimental results concerning the separated aperture (or waveguide beyond cutoff) buried mine detection scheme. The primary purpose of this research effort is to contribute to an engineering database to be used in a long term research program directed toward the development of a complete understanding of the fundamental electromagnetic principles underlying the separated aperture mine detection technique and to assess the general feasibility of separated aperture mine detectors. KEYWORDS: LAND MINES; MINE DETECTION. (RH) 					
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SECTION I. INTRODUCTION

FUNDAMENTAL OPERATING PRINCIPLES OF THE WAVEGUIDE BEYOND CUTOFF BURIED MINE DETECTION SCHEME

Figure 1 (see Appendix A) shows a simplified representation of the separated aperture or waveguide beyond cutoff mine detection scheme. As shown, the sensor is composed of a transmit and receive dipole pair separated by a metallic septum. Each dipole resides within a corner reflector. For a fixed input power, the output power measured at the receiving dipole is monitored. As the sensor head moves over the surface of the earth, the received power varies. When the sensor head is over uniform background (no mine present) very little power is received. There is a significant increase in received power when the sensor head is over a mine.

Although the separated aperture approach to mine detection is simple, it has certain, very desirable features that are not shared by other electromagnetic mine detection methods. Electromagnetic identification of buried mines requires a transmitter and receiver: energy from the transmitter penetrates the earth surface, interacts with the buried mine, and is then coupled into the receiver for detection. Unfortunately, a rather large amount of energy can be directly coupled from transmitter to receiver or reflected from the air-soil interface and coupled into the receiver. Energy at the receiver which interacts with the mine (the signal) can be quite small in comparison with this direct and ground reflected energy (the clutter). The advantage of the separated aperture approach over other electromagnetic detection techniques is that, under proper operating conditions, the direct and ground reflected signals are substantially suppressed in comparison with the return from the buried mine. The metallic septum forms a waveguide with the earth's surface and when the septum-earth separation is small, this waveguide is below cutoff resulting in an exponential attenuation of the direct and ground reflected signals and a vastly improved signal-to-clutter ratio. In fact, according to one source, the waveguide beyond cutoff sensor exhibited the best signal-to-clutter ratio of any technique ever attempted.¹

HISTORICAL PERSPECTIVE

As discussed in the report, *MERADCOM Mine Detection Program: 1960-1980*:

"The waveguide beyond cutoff concept was discovered in the 50's and implemented in a portable (hand held) mine detector, the PRS-6, which was never type classified. Experimental data collected under controlled conditions exhibited the best signal-to-clutter ratio of any technique ever attempted, and tests against the PRS-4 revealed it to be superior in both detection and false-alarm rejection. Its major drawback was its height sensitivity which produced a false alarm signal when the antenna reached a height of one-half wavelength. The PRS-4 and PRS-7, which had lower detection capability, merely ceased to detect without alarm and had, therefore, greater user acceptance."¹

Research leading to a vehicular-mounted road mine detection system based on the separated aperture approach was conducted from the early 1970s to April 1982. The development effort was undertaken by the Belvoir RD&E Center with technical support from the National Bureau of Standards (NBS) (now the National Institute of Standards and Technology (NIST)) and the Cubic Corporation. According to Report 2412, *Vehicle-Mounted Road Mine Detector System (VMRMDs), AN/VRS-5*:

"Concentrated investigative efforts were conducted by the Bureau of Standards in the antenna design and frequency determinations. The Cubic Corporation was contracted to proceed in the tasks of electronic signal transposing for field use and mechanical development for vehicle-mounted field use." ²

A Vehicle-Mounted Road Mine Detection System (VMRMDs), AN/VRS-5, shown in Figure 2 (see Appendix A), was eventually constructed and subjected to Operational Testing (OTII) by the Armor and Engineer Board at Fort Knox, KY, between January and April 1982. Many system deficiencies were noted during this test, the most serious of which was the extremely poor mine detection rates of mines buried in high-moisture content soils and mines subjected to vehicle wheel or tread compaction. Again, according to Report 2412:

"During the same time period (between January and April 1982), TRADOC determined that there was no longer a requirement for a vehicle-mounted mine detector which could be used only on roads or other flat terrain. By letter US Army Engineer School (TRADOC proponent), ATZA-CDM, 9 April 1984, withdrew the requirement for the system causing DARCOM (now AMC) to direct termination of the program." ²

LESSONS LEARNED AND ISSUES RAISED

Although the VMRMDs previously discussed was never accepted by the Army, the separated aperture approach to mine detection, for reasons outlined above, is nevertheless considered by knowledgeable individuals at the Belvoir RD&E Center to be one of the best mine-detection schemes ever developed both in terms of detection reliability and false-alarm rejection. The technique is, however, limited to relatively level, sparsely vegetated terrain since the septum earth separation must be small to achieve the waveguide below cutoff effect discussed above.

Much was learned from past theoretical and experimental research efforts with the separated aperture mine detection technique. However, the eventual failure of the AN/VRS-5 exposed several important limitations that must be addressed before another full scale development program can be pursued. Some of the more important issues which must be resolved are as follows:

- 1 A mine buried in soil with high moisture content seems to be extremely difficult to detect and, as expected, the situation is exacerbated as the mine is buried deeper. Past research efforts were conducted with two types of dipoles, a narrow band printed circuit dipole (PC dipole) used by the Cubic Corporation, and a relatively broadband brass dipole used by NBS. It was observed that the PC dipoles give good detection performance with mines buried in homogeneous, relatively dry soil. However, the response in moist or wet soil is known to degrade. Some evidence exists supporting the notion that the broadband dipole would perform much better under these conditions. Preliminary NBS research also

indicated that some frequencies penetrate moist soils much more efficiently than do others so that a "window of opportunity" may exist which can be used to enhance detection under wet conditions. These rumors and conjectures must be carefully investigated. Even if it turns out that the separated aperture approach simply does not work well in moist soil, this will still be important information regarding the generation of realistic specifications for a prototype vehicular and/or hand-held mine detector.

2 The operating bandwidth and frequency sampling interval must be optimized for best detection performance. The optimum choice for one set of conditions (e.g., dry soil) might not at all be optimum under other conditions (e.g., wet soil). Expansion at the lower end of the bandwidth could improve the performance in wet and heterogeneous soils. (Because of skin effect, low frequency energy generally penetrates lossy soil more effectively than does high frequency energy.³) NBS research indicated a greater confidence in 10 MHz interval bandwidth readings than with 20 MHz. Any "new start" program should carefully review the bandwidth/sampling interval issue.

Other deficiencies were outlined in Report 2412.² Throughout the history of the VMRMDS development, there was only one known correlation of simulated mines with those having high explosives (without fusing). In one test,⁴ it was observed that 11 of 14 runs over an explosive-filled mine resulted in lower responses than "identical" runs over wax-filled mines. It was recommended that a greater in-depth study be initiated to correlate explosive-filled with inert-filled responses.

It was also noted that soil compaction by vehicle passage, especially tracked vehicles, invariably resulted in greater attenuation of the signal return. Naturally, the question arises, "Should a VMRMDS-like system be required to detect mines that have been run over several times prior to detonation?" (Remotely activated mines would not necessarily detonate on first pass.) It was recommended that this issue be examined when drafting future requirements documents.

According to Report 2412, the AN/VRS-5 signal display unit was, to say the least, not very "user friendly."

"Interpretations of the pictures on the display is subjective and requires considerable practice and familiarization . . . In the real battle scenario, the decision making by the operator would prove to be a fatiguing, traumatic experience . . . A misinterpretation of an actual live mine detection could result in a terminal detonation." ²

In summary, it is probably worthwhile to consider the final paragraph of the conclusions section of Report 2412:

"This appraisal of the AN/VRS-5 development program is somewhat critical since it is relatively easy to find flaws in hindsight. It should be remembered that the pressures of schedules, funding, and personnel perturbations do not appear in the overall picture but are a large part of program management. The development of this system demonstrates clearly that the technology offers considerable promise of detecting soil/mine anomalies under proper conditions but there are definite physical limitations which must be recognized. The system, itself, could even be developed to recognize and signal these limitations."²

PRESENT EFFORTS AND FUTURE PLANS

Because of the many attractive features of the separated aperture buried mine detection scheme, the Belvoir Countermine Technology Division has decided to initiate a new long term research program dedicated to the development of a complete understanding of the fundamental electromagnetic principles underlying this approach and to assess the general feasibility of separated aperture mine detectors.

At present, the authors of this report are conducting carefully controlled measurements at the Center's mine detection research facility. Results include measurements with both the printed circuit and broadband brass dipole antennas. To date, all experiments have been conducted in dry, loamy soil but experiments in moist and saturated soils are planned for the near future. The measurement setup and experimental results are described in detail below.

The National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards (NBS)) is under contract to the Center to provide guidance and assist Center personnel in the in-house measurement program mentioned above. They have been asked to generate a summary report of past NBS research efforts on the VMRMDS program. NIST will also provide the Center with a test fixture which can be used with the Center's Hewlett Packard 8753A RF Network Analyzer to measure the constitutive parameters (complex permittivity) of soils with varying moisture content.

The separated aperture sensor may respond to a rock or root in somewhat the same way it responds to a buried mine, resulting in an unacceptably high false alarm rate. At the present time Dr. Bernard Widrow and his graduate students at Stanford University, through support from the Center, are investigating the possibility of using a neural network with the separated aperture sensor to facilitate discrimination.⁵ Neural networks, not unlike human beings, require "training" to become proficient at a task. In this case, the neural network requires a large amount of sensor data to "learn" the difference between a buried mine and background (no mine, but possibly other mine-like objects). Recently, a fairly extensive experimental data collection program has been completed. This data has been transferred to Stanford and will be used to train a neural network to discriminate between mines and other background anomalies (clutter) and between mine types.

SECTION II. EXPERIMENTAL RESULTS

DATA COLLECTION SYSTEM

Figure 3 (see Appendix A for all figures) shows a side view of the experimental data collection system which consists of a motorized three-wheeled cart, Hewlett Packard 8753 A network analyzer, Hewlett Packard Multi-programmer, and separated aperture sensor head. A front view of the system is shown in Figure 4. The height of the sensor head above the soil surface is adjusted using the hand crank and horizontal movement of the sensor is automatically controlled by a worm gear attached to a stepper motor. As shown in Figure 5, the test equipment is controlled by a Hewlett Packard 9000 model 236 desktop computer via a fiber optic link. Experimental data collected from the network analyzer is stored on a 3.5 inch floppy disk.

BROADBAND AND PRINTED CIRCUIT SENSOR HEADS

Figure 6 shows a close-up photograph of the 790 MHz sensor head which is composed of a transmit and receive broadband dipole pair separated by a metallic septum. Each broadband dipole resides within a corner reflector. The critical dimensions of the 790 MHz sensor head and broadband dipole are given in Figure 7. A few experiments were conducted using a broadband 1 GHz sensor and the critical dimensions for this head are shown in Figure 8. A 790 MHz sensor head using printed circuit dipoles is shown in Figure 9.

The bandwidth of the 790 MHz broadband and printed circuit sensor heads of Figures 6 and 9 is examined in Figure 10. Reflection coefficient (S_{11} dB) or standing wave ratio (SWR) is measured as a function of frequency for various heights of the sensor over dry, loamy soil. Figure 10a compares the reflection coefficient (S_{11} in dB) of the broadband and printed circuit dipoles for the frequency range from 300 kHz to 3 GHz when the sensors are 1 inch above the soil. Both dipoles are designed to resonate near 800 MHz and it is clear that the broadband dipole does indeed have greater bandwidth than the printed circuit dipole. An expanded view of this comparison is given in Figure 10d. Here, the SWR of the PC sensor is less than 3 from about .78 GHz to .82 GHz (a 40 MHz bandwidth), whereas the broadband sensor has an SWR less than 3 from about .75 GHz to .88 GHz (a 130 MHz bandwidth). In short, for this configuration, the broadband sensor returns less than 25% of the incident power to the source over a 130 MHz band; the PC sensor only performs that well over a 40 MHz band. Therefore, the broadband sensor has slightly more than three times the bandwidth of the PC sensor. Figures 10b and 10c demonstrate how the performance of the broadband and PC sensors vary for various sensor heights (1, 3, 5, and 7 inches).

EXPERIMENTAL PROCEDURE

This overview of the experimental test configuration defines the many variables which must be examined in order to develop a good understanding of the separated aperture dielectric anomaly

detection scheme. Figure 11 is a scale drawing of the experimental configuration showing the 790 MHz broadband sensor parallel to and at a height H above the soil surface. A dielectric anomaly, usually a 12 x 12 x 3 inch nylon block, is buried at a depth D below the soil surface. For most of the experimental results presented here, the sensor head is scanned in 1.5-inch increments directly over the anomaly (receive dipole passes over the anomaly first). As shown in Figure 11, measurements are made at 27 positions for a total horizontal scan of 39 inches. At each horizontal position, the network analyzer is used to measure the transmission coefficient (S_{21}), complex ratio of voltage at the output of the receive dipole to the voltage at the input of the transmit dipole, at 8 MHz intervals starting at 600 MHz and ending at 1,000 MHz—51 frequency samples over a 400 MHz band. Since the dipoles are resonant near 800 MHz, the transmission coefficient is measured from 200 MHz below resonance to 200 MHz above resonance. A 6-inch septum width was used for most of the data taken with the 790 MHz broadband sensor; however, the septum width can be adjusted.

Some measurements were made with the 790 MHz sensor head rotated 90 degrees so that the transmit and receive dipoles were parallel to the scan direction. Also, a few measurements were made with the 790 MHz PC dipole sensor and the 1 GHz broadband sensor. At one point, the resonant frequency of the 790 MHz sensor was lowered to 496 MHz by extending the length of the dipole arms via a metal sleeve. No other part of the sensor head was modified. As discussed in more detail later, results with this modified sensor were not very promising. Dielectric anomalies of styrofoam and water were also examined. The water was placed in a plastic garbage bag and then carefully lowered into a hole measuring 12 x 12 x 3 inches.

SOIL AND ANOMALY CONSTITUTIVE PARAMETERS

As one might expect, the ability to detect an anomaly buried in soil depends, among other things, on how different the electrical properties of the anomaly are from those of the background soil. It also depends on how much the soil attenuates electromagnetic energy. Electromagnetic energy, which must penetrate deep into lossy earth to interact with an anomaly, will be hopelessly lost in the noise by the time it reaches the receiver.

All the experimental results presented here were conducted in fairly dry, loamy soil with a moisture content of 6% by weight. The electrical properties of the soil were measured using a shielded open circuit coaxial line technique developed by researchers at the NIST.⁶ The complex permittivity, $\hat{\epsilon} = \epsilon' - j\epsilon'' = \epsilon_0(\epsilon_r' - j\epsilon_r'')$ of the soil at 600 MHz, 790 MHz, and 1 GHz (the operating frequency range of the 790 MHz sensor) is $\epsilon_0(2.8842 - j0.3712)$, $\epsilon_0(2.8774 - j0.4443)$, and $\epsilon_0(2.8806 - j0.5176)$, respectively, with $\epsilon_0 = 8.854 \times 10^{-12}$ F/m. It can easily be shown that a 790 MHz plane wave would be attenuated by 10 dB after propagating about 3.5 feet in this soil.⁷

As mentioned above, dielectric anomalies of styrofoam, nylon, and water were investigated. Styrofoam has electrical properties very similar to those of air; at 10 MHz, the permittivity of styrofoam is ϵ_0 (1.03 - j 0.0002). A nylon block with dimensions 12 x 12 x 3 inches was used in the majority of the experiments; at 100 MHz, nylon has a permittivity of ϵ_0 (3.16 - j 0.0660). A few experiments were performed using water as the anomaly; water has a dielectric constant at 300 MHz and 25°C of ϵ_0 (77.5 - j1.25). Permittivity data was taken from Harrington.⁷ It is worth noting that styrofoam, nylon, and water have dielectric constants (real part of complex permittivity) less than, approximately equal to, and much greater than the loamy soil background.

COUPLING AS A FUNCTION OF SENSOR HEIGHT

Figure 12 plots the transmission coefficient for the 790 MHz broadband sensor as a function of frequency for various sensor heights. Proper operation of the separated aperture sensor requires that the direct signal coupled under the airspace between the septum and earth not mask the relatively weak signal from the buried dielectric anomaly. When the sensor is close to the earth, the septum and earth function like a waveguide that is below cutoff and thus the direct signal is significantly attenuated. From Figure 12, the coupling near resonance is suppressed by about 25 dB for heights of 1, 2, and 3 inches compared with coupling at a height of 6 inches. It will be shown later that this sensor head generally does not function properly for heights greater than about 4 inches.

SOIL HOMOGENEITY AND CONTROL OF SENSOR HEIGHT

Ideally, for a fixed sensor height, the transmission coefficient vs. frequency data should be independent of horizontal sensor position provided that the soil is homogeneous. Dirt clods and packing can create background soil inhomogeneities and the sensor height will be a function of position if the soil is not level. It is important to eliminate problems such as these so that any fluctuations in measured transmission coefficient can be solely attributed to the buried anomaly.

In an attempt to remedy these problems, the entire experimental test bed was overturned with a shovel down to a depth of about 2.5 feet, and the soil was vigorously chopped with a pickax to eliminate any dirt clods. Planks 4 x 4 inches in cross section were buried and leveled at 5-foot intervals across the test area. Using another plank, the soil between these parallel planks was leveled over the entire test area. A 4 x 8 foot sheet of 5/8 inch thick plywood was laid down over one end of the test bed so that the three-wheeled cart (see Figures 3 and 4) could move up and back on a stable platform without digging ruts into the soil. In short, these precautions were taken in order to ensure that the sensor height remained constant over every horizontal scan and that the background soil was as free from inhomogeneities as possible.

Figures 13 and 14 quantify the degree to which the soil can be viewed as a homogeneous background. Figure 13 provides plots of the transmission coefficient as a function of frequency for sensor heights of 1, 2, 3, 4, 5, and 6 inches at the far left (position 1), center (position 4), and far right (position 27) of a

horizontal scan (see Figure 11). For sensor heights of 1 and 2 inches, the frequency responses at positions 1 and 14 are more or less the same (at least below 850 MHz), but the general shape of the response at position 27 seems to differ significantly from the response at positions 1 and 14, and at some frequencies by as much as 10 dB. At frequencies above 840 MHz, all three curves are somewhat different.

At sensor heights of 3 and 4 inches, the soil "looks" fairly homogeneous and at sensor heights of 5 and 6 inches, the soil "looks" perfectly homogeneous. It should be noted that as the sensor height increases, more and more energy is coupled directly through the airspace between the soil surface and septum. Thus, when the sensor height is large, the proportion of energy coupled through the soil is small compared with the direct coupled energy so that any soil inhomogeneities will be masked. (Compare the ordinate scale of Figures 13d, e, and f with those of Figures 13a, b, and c.)

Figure 14a and b provide a qualitative three-dimensional view of the soil background homogeneity as a function of frequency and position for sensor heights of 2 and 4 inches. Each figure is composed of 27 lines and each line corresponds to the transmission coefficient measured at the *i*th position along a horizontal scan. The first line in the foreground corresponds to the transmission coefficient measured at position 1 and the second line to measurements made at position 2, etc.

ABILITY OF 790 MHz SENSOR HEAD TO DETECT A BURIED NYLON BLOCK

Next, consider the ability of the broadband 790 MHz separated aperture sensor to detect a 12 x 12 x 3 inch nylon block buried at various depths in a background of relatively dry, loamy soil. Referring again to Figure 11, the transmission coefficient is measured at 27 positions in 1.5-inch increments across a horizontal scan for sensor heights of 1, 2, 3, 4, 5, and 6 inches, and nylon block depths of flush, 3, 6, 9, and 12 inches. (Note: The term *flush* indicates that the top of the nylon block is buried just under the surface of the soil, and a depth of 3 inches indicates that the top of the block is 3 inches below the soil surface, etc.) As previously mentioned, at each horizontal position, the transmission coefficient is measured at 51 discrete frequencies from 600 MHz to 1,000 MHz. The sensor dipoles are resonant near 790 MHz, and the sensor is scanned directly over the anomaly in such a way that the receive dipole passes over the anomaly first.

Transmission coefficient measurements will be a function of frequency, position, sensor height, and anomaly depth. In Figure 15, the anomaly is buried flush with the surface; in Figure 16, the anomaly is buried 3 inches deep, and so forth for Figures 17 and 18; and in Figure 19, the surface of the anomaly is 12 inches below the soil-air interface. Each figure has six plots corresponding to sensor heights of 1, 2, 3, 4, 5, and 6 inches. Each plot gives transmission coefficient (*S*₂₁) vs. frequency data at sensor positions 1 (to the far left of the anomaly), 14 (directly over the anomaly), and 27 (to the far right of the anomaly).

Figures 20 through 25 display exactly the same information as Figures 15 through 19 except in a different format. In Figures 20 through 25, the sensor height is the constant parameter rather than anomaly depth. In Figure 20, the sensor height is 2 inches above the soil; in Figure 21, the sensor is

3 inches above the soil; etc. Each figure has five plots corresponding to anomaly depths of flush, 3, 6, 9, and 12 inches. Each plot gives transmission coefficient (S_{21}) vs. frequency data at sensor positions 1, 14, and 27.

Several observations can be made from the above data. When the sensor height is less than about 4 inches, the response (S_{21}) at position 14 is generally greater than when the sensor is at position 1 or 27. This statement is generally true over the entire frequency range from 600 MHz to 1,000 MHz; in fact, at some frequencies (Figure 15a), the difference in anomaly and background response can be as large as 25 dB.

Recall that when the sensor is close to the soil surface and over homogeneous background, the waveguide formed between the septum and soil interface is below cutoff so that direct coupling between transmit and receive dipoles is small. When the sensor is close to the earth and directly over the anomaly, the anomaly provides an additional propagation path and consequently coupling between transmit and receive dipoles increases.

When the sensor height is greater than about 4 inches, it is no longer generally true that the response at position 14 is greater than at position 1 or 27. For example (from Figure 15f), for frequencies below about 820 MHz, the response at position 14 is less than the background response, and above 840 MHz the opposite is true.

At sensor heights greater than 4 inches, the waveguide formed between the septum and soil interface is no longer below cutoff and considerable direct coupling takes place. When the sensor is directly over the anomaly, coupling through the anomaly can either constructively or destructively interfere (add in or out of phase) with the direct coupling so that the net response can either be greater or less than the background response.

The difference between the response (S_{21}) at position 14—sensor over anomaly—and position 1 or 27—sensor away from the anomaly (the *difference response*)—generally decreases as the sensor height and/or anomaly depth increases. This result is expected and is merely a statement that for a given sensor height, the deeper the anomaly the harder it is to "see," and for a given depth, the anomaly becomes harder to "see" as the sensor height increases. From Figure 20, when the sensor is only 2 inches from the soil surface, the maximum difference response is at least 15 dB even when the anomaly is buried 12 inches below the surface. On the other hand, from Figure 23, when the sensor height is 4 inches above the soil, the difference response is small for anomaly depths greater than 3 inches. In short, acceptable performance can be expected for anomaly depths up to 6 inches provided the sensor height does not exceed 3 inches. This conclusion is valid only over the range of experimental conditions considered. Under different conditions (e.g., sensor design, anomaly size, soil type and moisture content, etc.) the result might be quite different. Moist or wet soil conditions, all other parameters held constant, might considerably reduce the range of anomaly depths and sensor heights over which acceptable performance could be expected.

SENSOR RESPONSE AS A FUNCTION OF POSITION

Another meaningful way to present the data obtained from the experiment depicted in Figure 11 is to plot the transmission coefficient as a function of position for fixed frequency. In Figure 26, the response vs. position of the broadband sensor at 796 MHz (the resonant frequency of the sensor dipoles) is given for sensor heights of 1, 3, 4, and 6 inches and anomaly (12 x 12 x 3 inch nylon block) depths of flush, 3, 6, 9, and 12 inches.

For sensor heights less than 4 inches and anomaly depths up to 6 inches, Figure 26 clearly shows that there is peak in the response when the sensor is directly over the anomaly. It is also interesting to note that there is often, but not always, a dip in the response curve on either side of the peak. This phenomenon is particularly pronounced for the case when the anomaly is buried just under the soil surface (flush) and the sensor is at a height of 4 inches (see Figure 26a). In this case, the dip to the left/right of the peak occurs when the leading edge of the septum just passes over the left/right edge of the anomaly.

As expected, as the anomaly depth or sensor height increases beyond 4 and 6 inches, respectively, the peak in the response becomes washed out. The peak for an anomaly depth of 9 inches and a sensor height of 4 inches (see Figure 26d) is actually below the background level. In this case, however, the dips associated with the septum passing over the edges of the anomaly still mark its position.

Figure 27 provides plots of S_{21} vs. position for various sensor heights and anomaly depths similar to the results provided in Figure 26, except that sensor has been rotated 90 degrees with respect to the direction of scan. Conclusions drawn regarding Figure 26 also apply to Figure 27. The dips in the response curve again occur just as the septum passes over the edge of the anomaly. Notice that rotating the sensor has broadened the response of Figure 27a relative to that of Figure 26a. As expected, this relative broadening is less pronounced as the anomaly depth or sensor height increases. Compare Figures 26e and 27c.

Figure 28 compares the response of the 1 GHz broadband sensor, 790 MHz broadband sensor, and a sensor formed by adding metallic sleeves to the dipoles of the 790 MHz sensor so that they resonate near 500 MHz. (Note that only the length of the dipole arms were increased in developing the "500 MHz sensor"; no other part of the 790 MHz septum or corner reflector geometry was modified.) The response of the 790 MHz sensor is clearly superior to either of the other two sensors. However, for a smaller anomaly, it is quite possible that the 1 GHz sensor would provide the best performance. One problem with the 1 GHz sensor is that its response degrades rather rapidly with height in comparison with the 796 MHz sensor. The response of the 1 GHz sensor is nearly flat at a height of 4 inches and is completely washed out at 5 inches. On the other hand, the 790 MHz sensor "sees" the anomaly very well at a height of 4 inches and "sees" the anomaly somewhat even at a height of 5 and 6 inches. The performance of the 500 MHz sensor leaves much to be desired. It was originally conjectured that the

height sensitivity could be improved by lowering the resonant frequency of the 790 MHz sensor to 500 MHz. This may be true, but the test results are inconclusive since the septum and reflector geometries were not also scaled. The fact that the 6-inch septum is electrically 62.5% shorter at 500 MHz than at 790 MHz leads one to conclude that it is very likely that there is too much direct coupling from transmit to receive dipole. It may also turn out that the resolution of the sensor at 500 MHz, even if properly scaled, would be less than desirable.

Figure 29 compares the response of the broadband 790 MHz sensor with that of the 790 MHz printed circuit (PC) sensor. Since both sensors are operated at very near their resonant frequencies (790 MHz), there is very little difference in their overall performance. Because the bandwidth of the broadband dipoles is significantly greater than the PC dipoles (see Figure 10) the broadband sensor may well perform better in a detection algorithm that utilizes a wider band of frequencies. Furthermore, under stringent conditions (e.g., anomalies buried deep in moist or wet soil), one would expect bandwidth to play an even more significant role in the detection process.

Figure 30 compares the response of 12 x 12 x 3 inch anomalies of styrofoam, nylon, and water buried just under the surface of dry, loamy soil. As previously mentioned, the water anomaly was created by filling a thin plastic garbage bag with the proper amount of water so as to just fill a hole of dimensions 12 x 12 x 3 inches. It is interesting to note that the largest response occurred for the styrofoam anomaly. In fact, styrofoam gave a fairly substantial response (relative to background) even at a sensor height of 6 inches. The response when the sensor was directly over water was always greater than when the sensor was over background. For heights of 5 and 6 inches, the response when the sensor was directly over nylon was less than when the sensor was over background.

SECTION III. SUMMARY

This report provided an overview of research efforts, both past and present, with the waveguide beyond cutoff or separated aperture dielectric anomaly detection scheme. Most significantly, it was stated that this sensor exhibits the best signal-to-clutter ratio of any electromagnetic detection technique ever attempted. It was pointed out that the improved signal-to-clutter ratio is obtained when the sensor is close to the ground and consequently this detection technique is most applicable to relatively level, sparsely vegetated terrain.

Previous research efforts with the separated aperture approach, which eventually led to a Vehicle-Mounted Road Mine Detector System (VMRMDS), AN/VRS-5,² were reviewed and it was pointed out that the AN/VRS-5 eventually failed because of its inability to detect mines buried deep in moist or wet soil. Other less serious deficiencies were discussed and it was concluded that the AN/VRS-5 efforts clearly demonstrated that the separated aperture technology offers considerable promise of detecting soil/mine anomalies under proper conditions, but there are definite physical limitations which must be recognized. It was pointed out that an increased operating bandwidth and frequency sampling interval might well improve the detection performance of the sensor, especially in wet soils. Furthermore, the printed circuit dipoles used in the AN/VRS-5 were inherently narrow band in comparison with the broadband brass dipoles used in the NIST research. Therefore, it was concluded that it is probably wise to use broadband brass dipoles in any further prototypes.

Present efforts and future plans were outlined. Additional experiments will be conducted at the Center's mine detection research facility by personnel in the Countermine Technology Division. Data recently collected at the Center has been transferred to Stanford University. Stanford plans to use this data to train a neural network to discriminate between mines and other background anomalies, clutter, and between mine types. The NIST has been asked to generate a summary report of past NIST research efforts on the VMRMDS program and to provide the Center with a test fixture which can be used with the Center's Hewlett Packard 8735-A Network Analyzer to measure the constitutive parameters of soils with varying moisture content.

OBSERVATIONS

In Section II of this report, the data collection system housed at the Center's mine detection research facility was described. The following important observations were made regarding the experimental data presented in this report:

1. The broadband sensor has roughly three times the bandwidth of the printed circuit (PC) sensor (see Figure 10).
2. Coupling from transmit to receive dipole is a relatively sensitive function of sensor height. Coupling near resonance (790 MHz) is suppressed by about 25 dB for sensor heights of 1, 2, and 3 inches compared with coupling at a height of 6 inches (see Figure 12).
3. In spite of efforts to eliminate dirt clods and soil packing, soil inhomogeneities were still apparent when the sensor was close (within 3 inches) to the earth. However, the return from a buried anomaly (a 12 x 12 x 3 inch nylon block buried less than 6 inches deep) is large compared with fluctuations in the return due to soil inhomogeneities.
4. A considerable amount of data was presented (see Figures 15 through 25) which characterized the ability of the 790 MHz sensor to detect a 12 x 12 x 3 inch nylon block buried in a background of relatively dry, loamy soil. Transmission coefficient data was presented as a function of frequency for sensor heights of 1, 2, 3, 4, 5, and 6 inches and nylon block depths of flush, 3, 6, 9, and 12 inches. Acceptable performance (the anomaly was "visible") can be expected for anomaly depths up to 6 inches provided the sensor height does not exceed 3 inches.
5. The sensor response as function of position at the resonant frequency of the sensor showed (see Figure 26) that there is a peak in the response when the sensor is directly over the anomaly and that there is a dip or null on either side of the peak. The dip to the left/right of the peak occurs when the leading edge of the septum just passes over the left/right edge of the buried anomaly. As the anomaly depth or sensor height increases beyond 6 and 4 inches, respectively, the peak in the response becomes washed out.
6. Rotating the sensor with respect to the direction of scan (see Figure 27) does not appreciably change the response.
7. The 790 MHz sensor performed better than either the 1 GHz or 500 MHz sensors (see Figure 28). For small anomalies, the 1 GHz sensor may perform best. The 500 MHz sensor may have performed better if the entire 790 MHz sensor was scaled—not just the dipoles.
8. As demonstrated in Figure 29, the broadband sensor performed about as well as the PC sensor. Over a broader range of frequencies, the broadband sensor would probably perform better than the PC sensor.
9. Figure 30 compares the response of 12 x 12 x 3 inch anomalies of styrofoam, nylon, and water buried just under the surface of dry, loamy soil. The largest response (relative to background) was obtained from the styrofoam anomaly.

RECOMMENDATIONS FOR FURTHER RESEARCH

The experimental data discussed in this report represents, at best, only a first order effort at completely characterizing the performance of the separated aperture dielectric anomaly detection scheme. Additional experiments will be required in order to gain a more complete comprehension of the operating characteristics and inherent limitations of this sensor.

As previously mentioned, the most serious problem with the AN/VRS-5 was its extremely poor detection rate of mines buried in high-moisture content soils. It was also conjectured that the broadband sensor would perform better than the PC sensor in moist or wet soils. Therefore, it is recommended that experiments conducted with the 12 x 12 x 3 inch nylon block be repeated in moist soils with both the broadband and PC sensor heads.

Most of the experimental data presented in this report dealt with the ability of the 790 MHz broadband sensor to detect a 12 x 12 x 3 inch nylon block buried in a background of dry, loamy soil. The 12 x 12 x 3 inch anomaly is about the same size as an antivehicular mine. Antipersonnel mines are typically smaller than antivehicular mines so that additional experimental data with a smaller anomaly and the 1 GHz sensor head would be required to optimize sensor design for detection of antipersonnel mines.

A considerable amount of experimental data was generated by NIST on the old VMRMDS program and, as previously mentioned, NIST is presently generating a written summary of these efforts. With this document in hand, it will be much easier to make an accurate assessment of the present state of the experimental database and to identify areas requiring further experimental efforts. Also, a substantially expanded experimental effort may be warranted depending on the relative success of the Stanford neural network research.

It is not difficult to see that an enormous experimental effort is required to completely characterize sensor performance. Unfortunately, even a thorough measurement program will not necessarily provide an adequate understanding of the fundamental mechanisms which control the detection process. Experimental techniques provide the "answer" but they do not necessarily provide a *reason* for the "answer." Therefore, it is recommended that a theoretical analysis be initiated with the goal of providing a complete understanding of the fundamental electromagnetic principles underlying the separated aperture mine detection technique.

In summary, a carefully orchestrated theoretical and experimental effort will probably provide the best possible opportunity to select optimum design specifications for a close-in mine detection prototype based on the separated aperture detection technique.

REFERENCES

1. R. V. Nolan, H. C. Egghart, L. Mittleman, R. L. Brooke, F. L. Roder, D. L. Gravette, *MERADCOM Mine Detection Program: 1960-1980*, Belvoir RD&E Center [formerly MERADCOM], Fort Belvoir, VA 22060-5606.
2. Donald L. Martin, *Vehicle-Mounted Road Mine Detector System (VMRMDS), AN/VRS-5*, Belvoir RD&E Center Report No. 2412, Fort Belvoir, VA, October 1984.
3. W. H. Hayt, *Engineering Electromagnetics - Fourth Edition*, pp. 398-405; 431; McGraw-Hill Book Company, Inc., New York, 1981.
4. Douglas Conley, *Test Results, Vehicle-Mounted Road Mine Detector System, Camp Bullis and Southwest Research Institute Test Sites*, Southwest Research Institute Internal Report, March 1976.
5. Bernard Widrow and Rodney Winter, *Neural Nets for Adaptive Filtering and Adaptive Pattern Recognition*, Computer, published monthly by the Computer Society of the IEEE, Vol. 21, No. 3, pp. 25-39, March 1988.
6. Howard E. Bussey, *Dielectric Measurements in a Shielded Open Circuit Coaxial Line*, IEEE Transactions on Instrumentation and Measurement, Vol. IM-29, No. 2, June 1980.
7. R. F. Harrington, *Time-Harmonic Electromagnetic Fields*, pp. 50-51; 451-455, McGraw Hill Book Company, Inc., New York, 1961.

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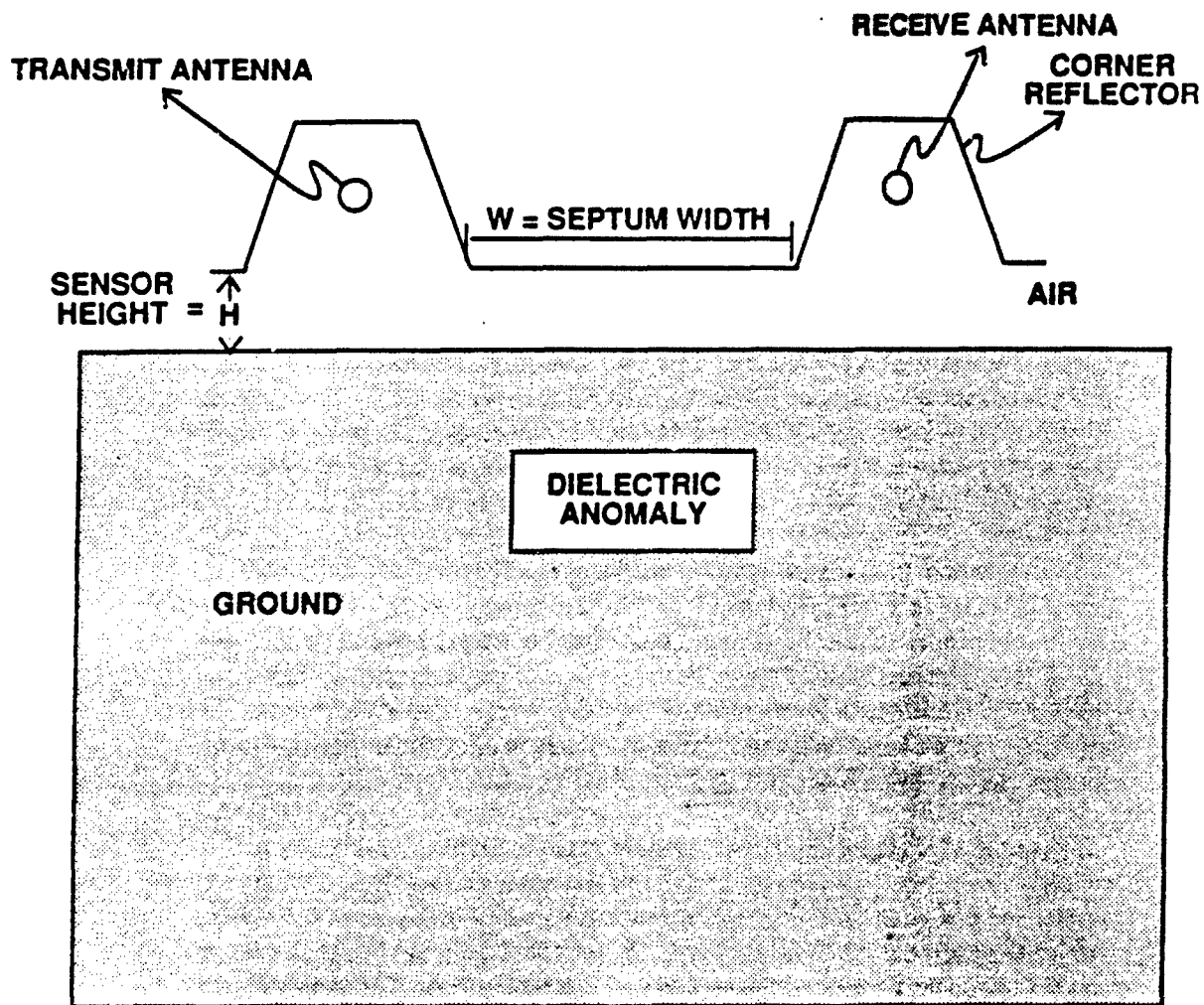


Figure 1. Simple schematic of the separated aperture or waveguide beyond cutoff mine detection system. When the sensor is over homogeneous earth (no mine present), very little power is received. There is a significant increase in received power when the sensor is over a mine. Best mine detection performance requires careful optimization of sensor parameters (i.e., sensor height, septum width, etc.)

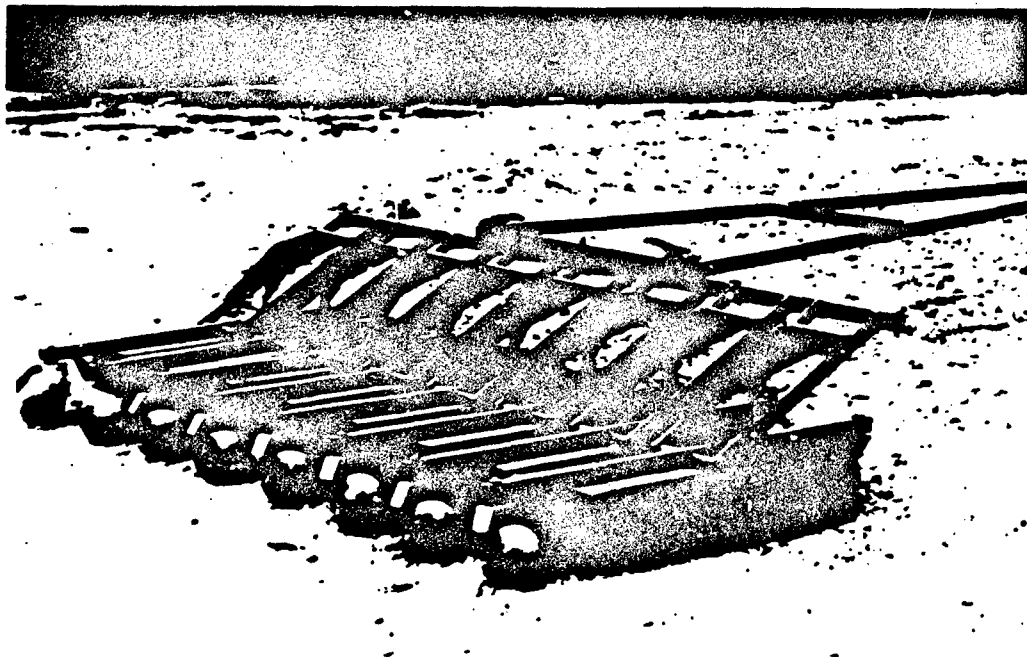


Figure 2. Close-in front view of AN/VRS-5 detector

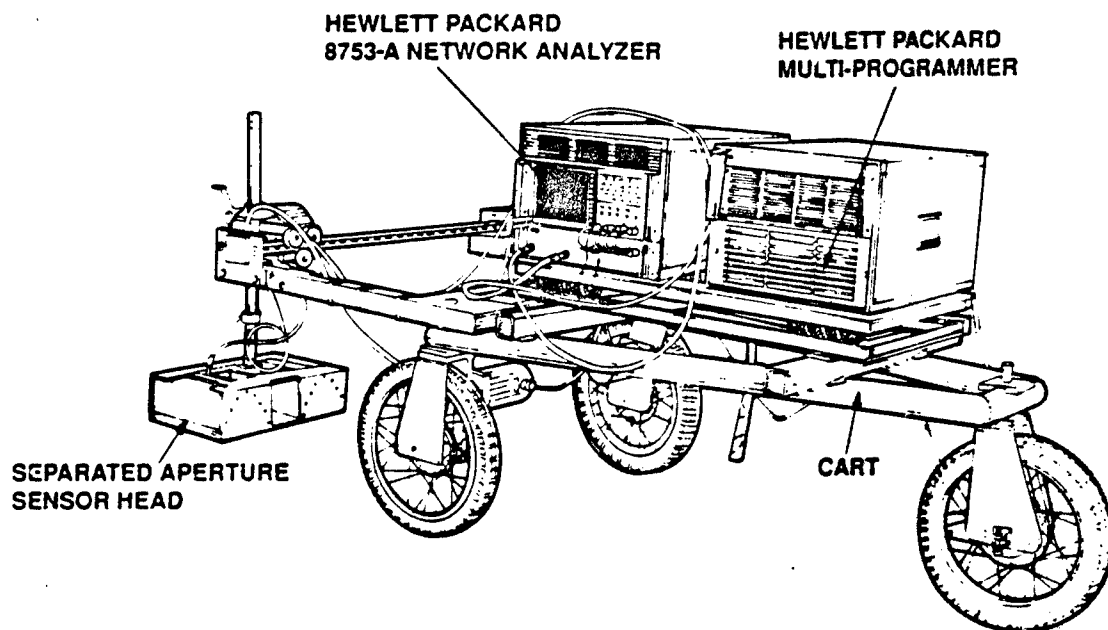


Figure 3. Side view of experimental setup consisting of motorized three-wheeled cart, Hewlett Packard 8753-A network analyzer and multi-programmer, and separated aperture sensor head

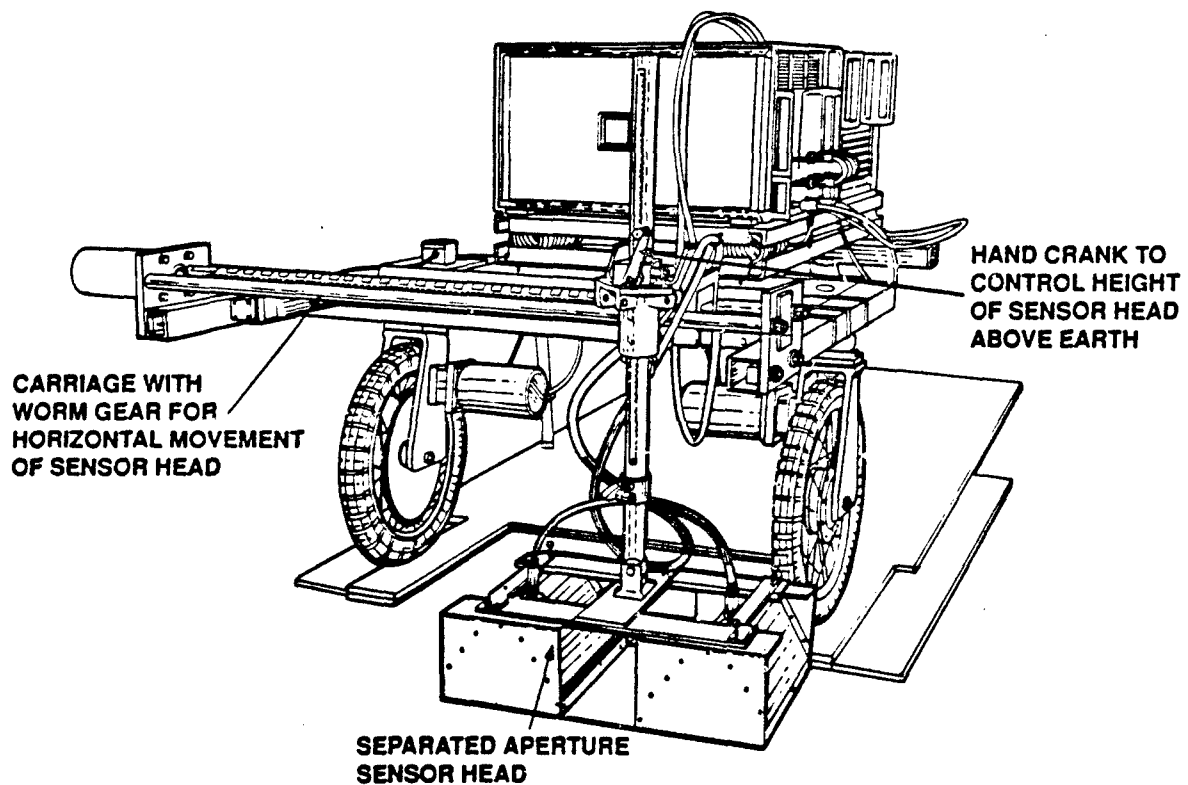


Figure 4. Front view of experimental test setup showing sensor head, hand crank to control height of sensor head above earth, and carriage with worm gear for horizontal movement of sensor head

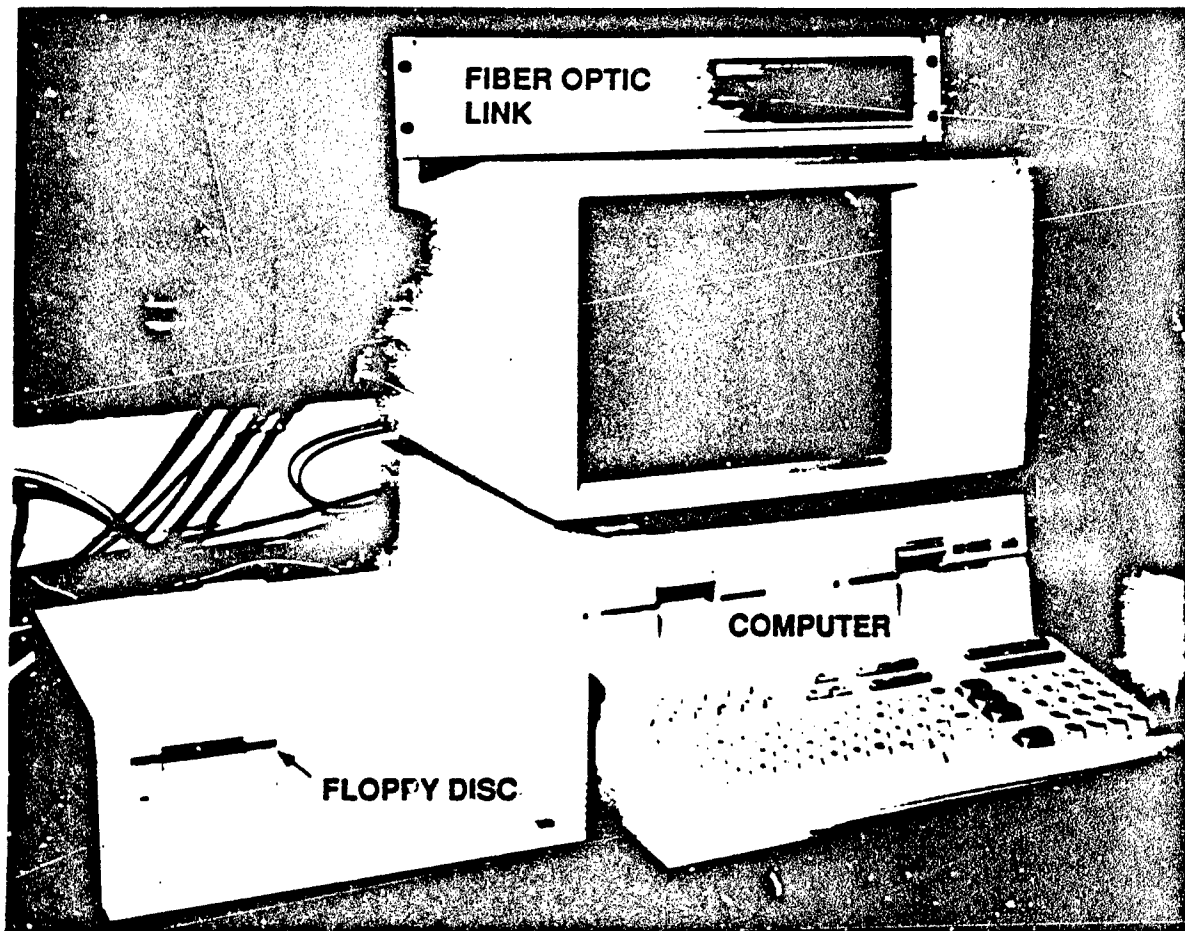


Figure 5. Hewlett Packard 9000 Model 236 desktop computer used to control, via a fiber optic link, the experimental test setup of Figures 3 and 4. Experimental data collected from the network analyzer is stored on a $3\frac{1}{2}$ inch floppy disc

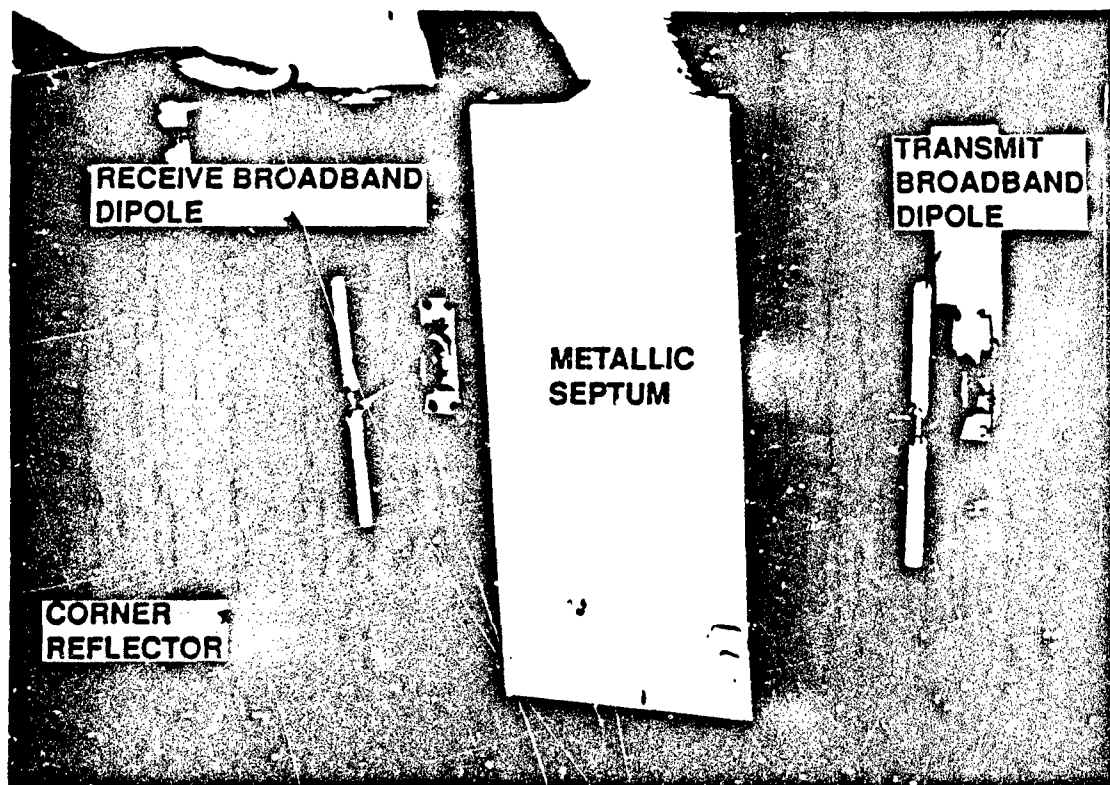


Figure 6. Close up photograph of 790 MHz sensor head, composed of a transmit and receive broadband dipole pair, separated by a metallic septum; each broadband dipole resides within a corner reflector

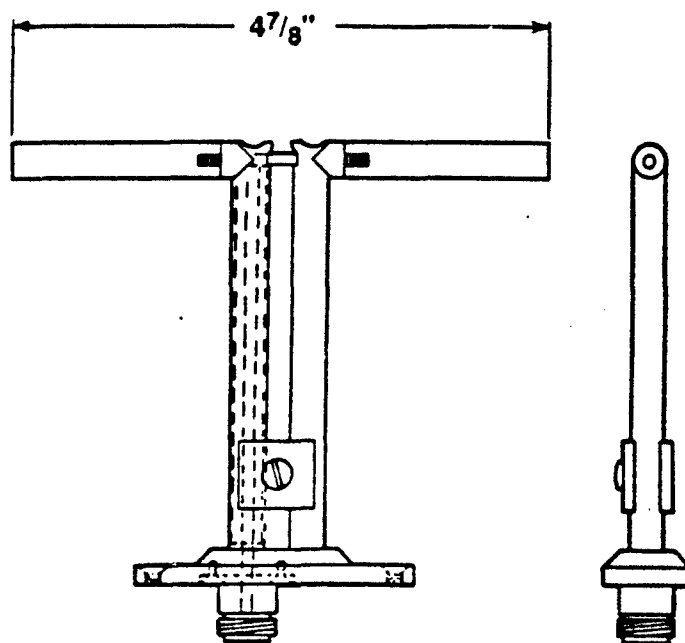
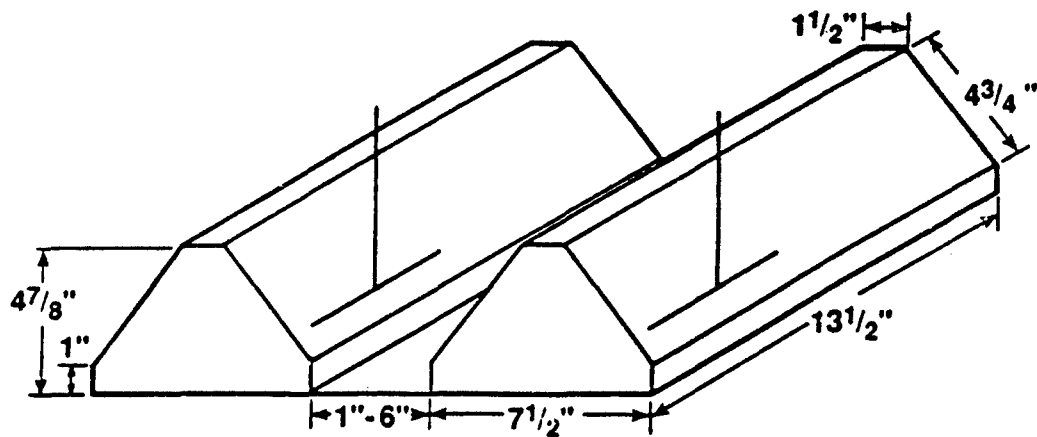


Figure 7. Critical dimensions of 790 MHz sensor head and 790 MHz broadband dipole

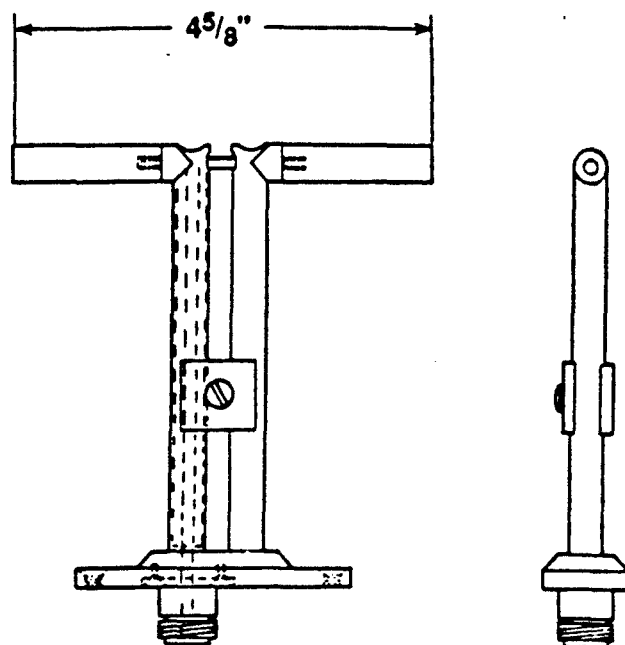
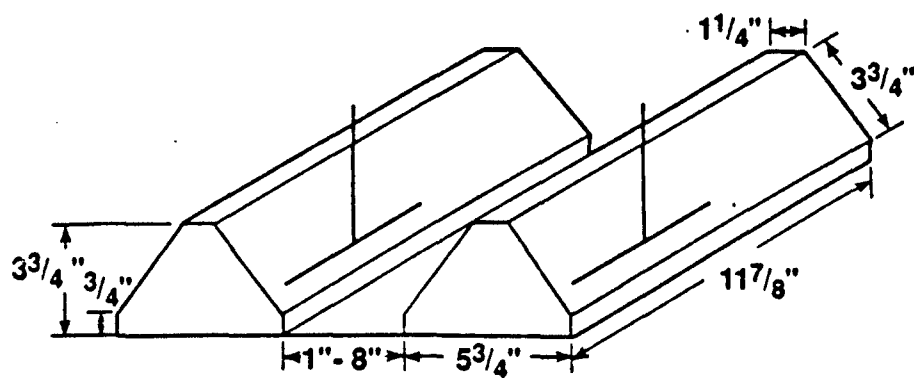


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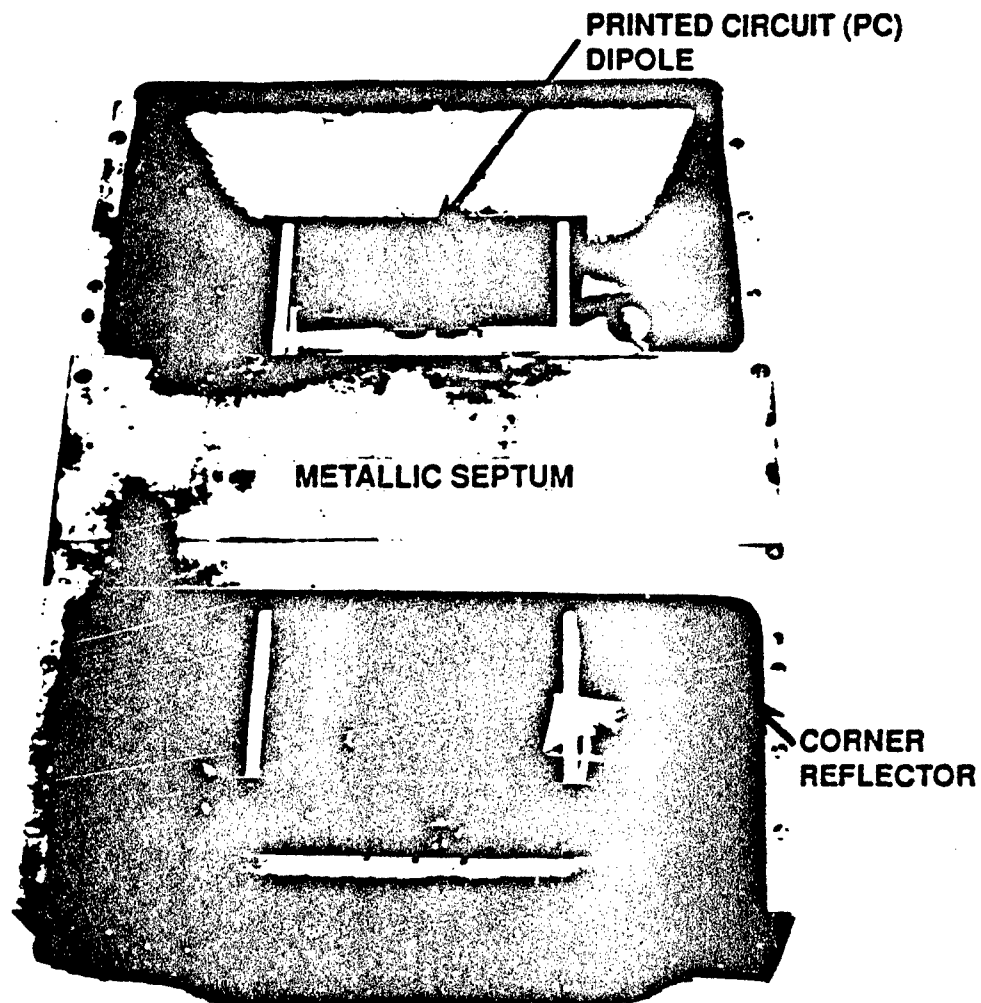
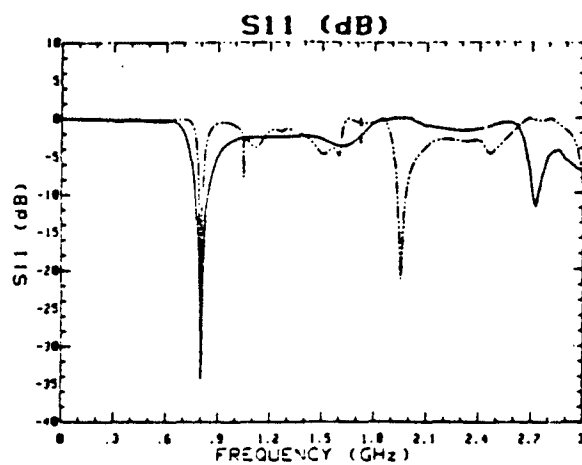
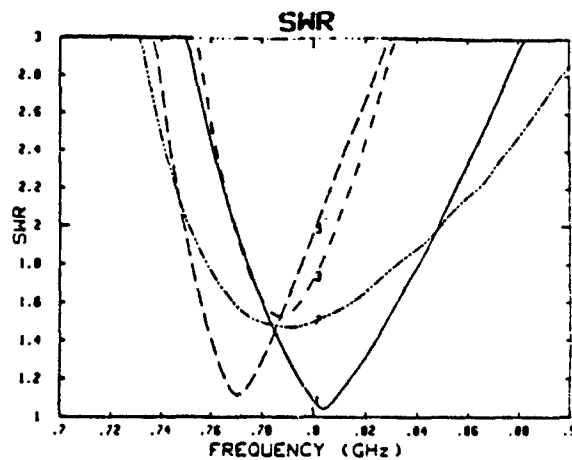


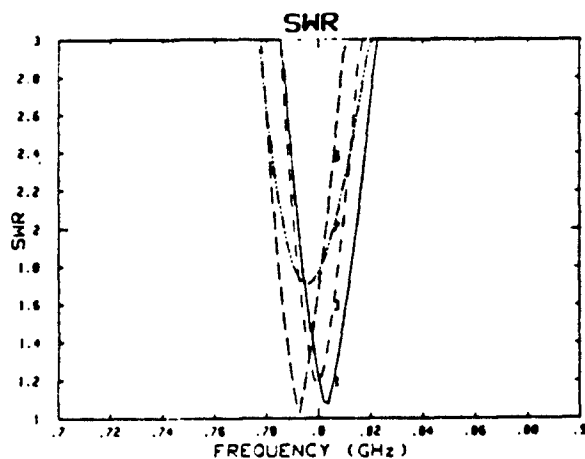
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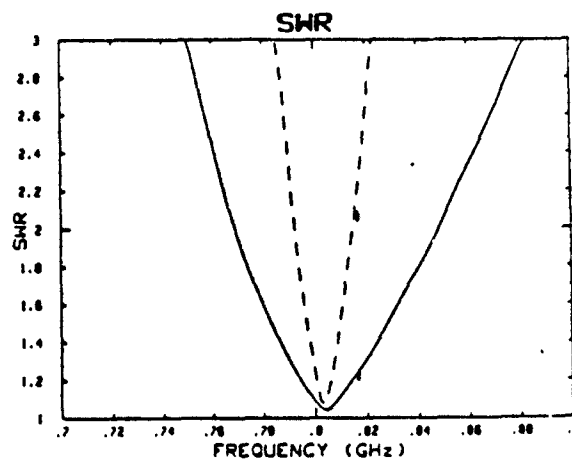
a)



b)



c)



d)

Figure 10. Reflection coefficient (S11 dB) or standing wave ratio (SWR) as a function of frequency for broadband and printed circuit (PC) dipoles. Measurements were made with the dipoles in the sensor head (see Figures 6 and 9) with the sensor head at various heights above the earth (dry, loamy soil):

- a) broadband dipole (—), PC dipole (---) for a 1 inch sensor height
- b) broadband dipole for sensor heights of 1, 3, 5, and 7 inches
- c) PC dipole for sensor heights of 1, 3, 5, and 7 inches
- d) broadband dipole (—), PC dipole (—) for a sensor height of 1 inch

LINEAR SCALE INDEXES 0 1.5 3 4.5 6.0 7.5 9 10.5 12 13.5 15 16.5 18 19.5 21 22.5 24 25.5 27 28.5 30 31.5 33 34.5 36 37.5 39

PORTION 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

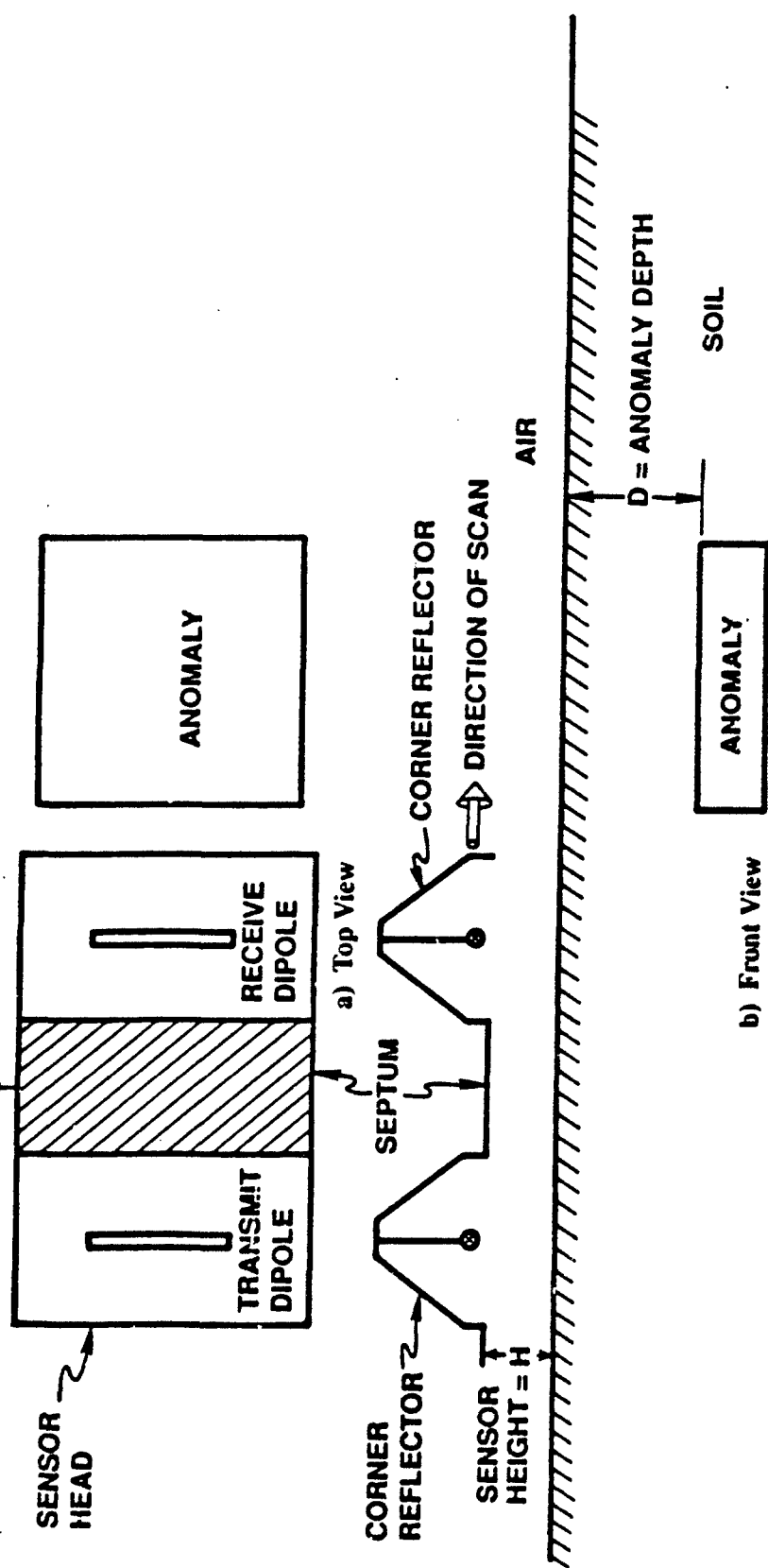


Figure 11. Scale drawing of experimental configuration showing 790 MHz sensor head (see Figure 6) parallel to and at a height H above the soil surface and dielectric anomaly ($12 \times 12 \times 3$ inches) buried at depth D below the soil surface. The sensor head is scanned directly over the anomaly in the direction shown (receive dipole passes over the anomaly first) in 1.5-inch increments for a total horizontal scan of 39 inches. The broadband dipoles are resonant at 790 MHz (see Figure 10). The sensor head septum width is adjustable in 1-inch increments over a range from 1 to 6 inches; however, for most of the data shown here, the septum width is held fixed at 6 inches

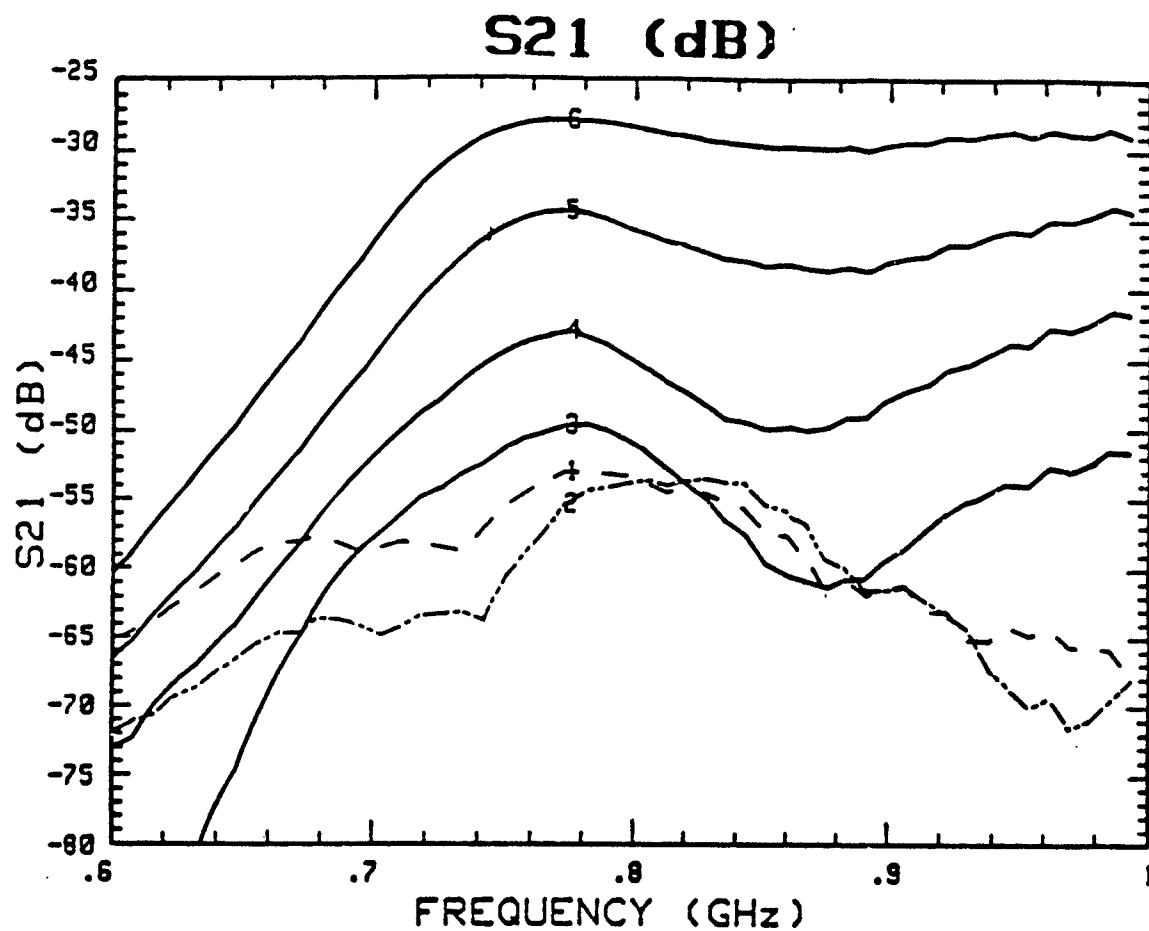
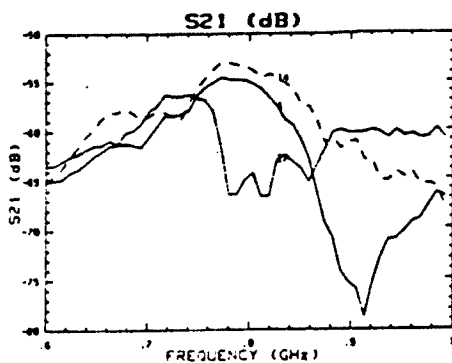
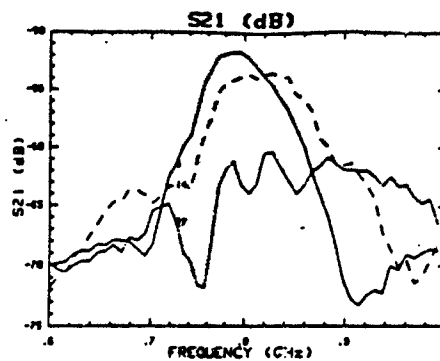


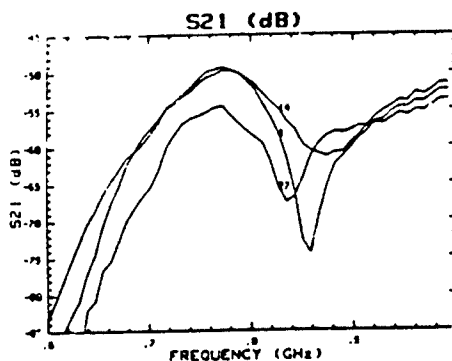
Figure 12. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil for broadband sensor heights of 1, 2, 3, 4, 5, and 6 inches; no dielectric anomaly present



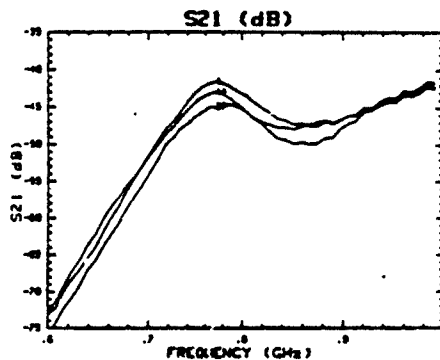
a) Sensor Height = 1 inch



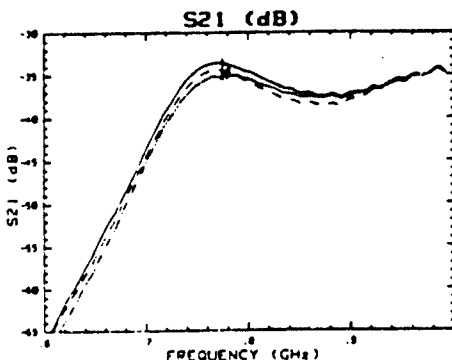
b) Sensor Height = 2 inches



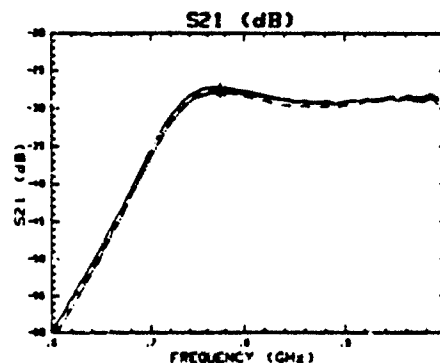
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

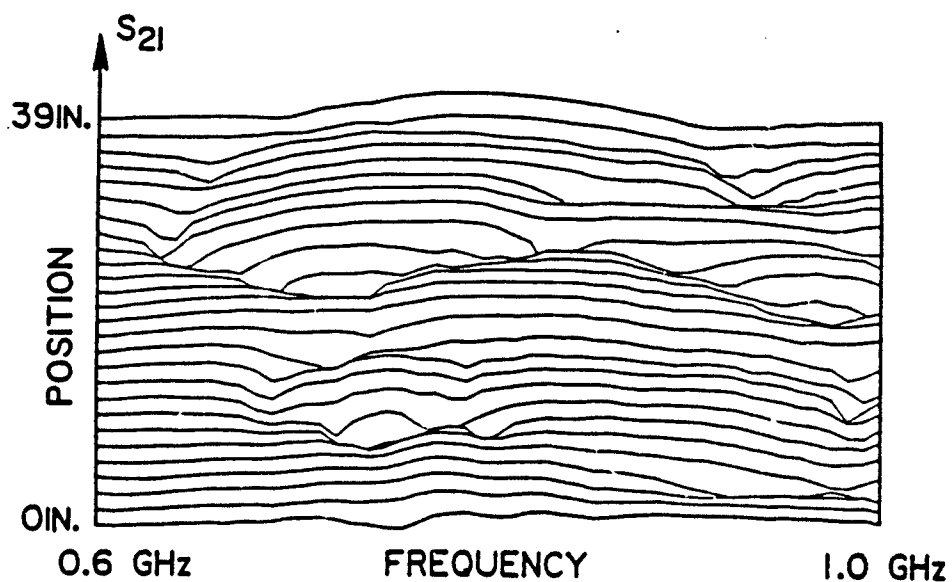


e) Sensor Height = 5 inches

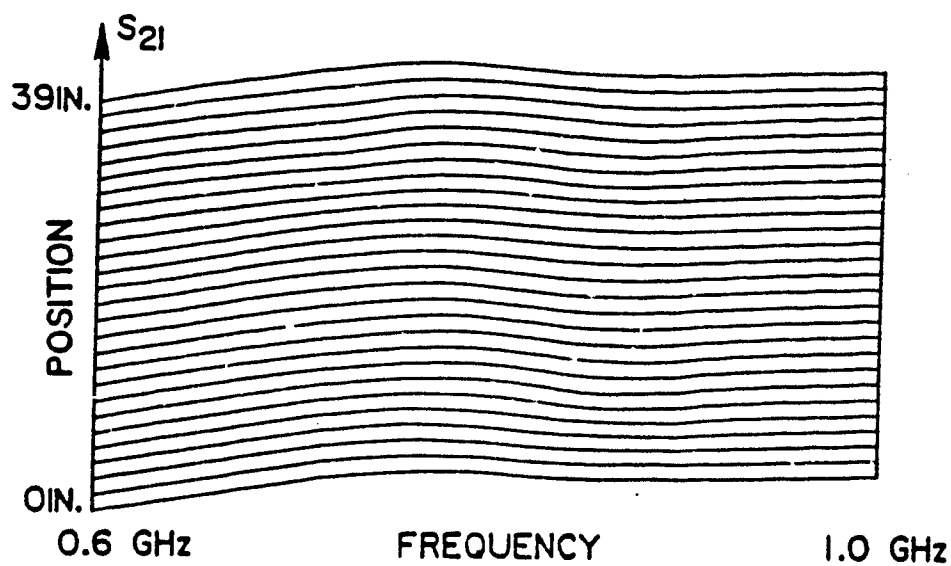


f) Sensor Height = 6 inches

Figure 13. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil with no dielectric anomaly present. In each figure curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center and far right of a 39-inch horizontal scan. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil

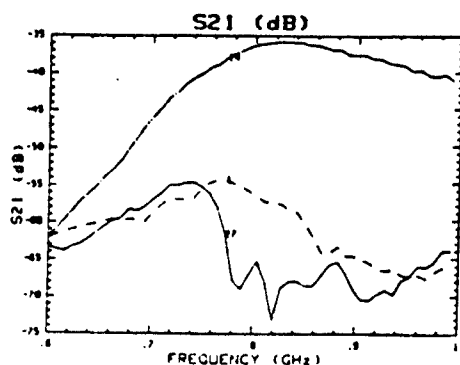


a) Sensor Height = 2 inches

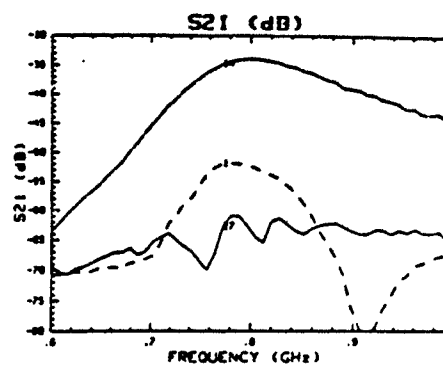


b) Sensor Height = 4 inches

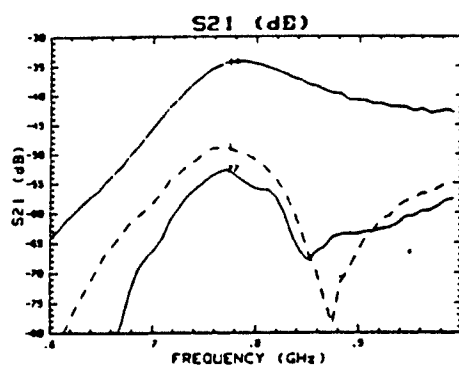
Figure 14. Measurement of transmission coefficient (S_{21}) as a function of frequency and sensor position. The broadband sensor is scanned over dry, loamy soil at a height of: a) 2 inches; b) 4 inches



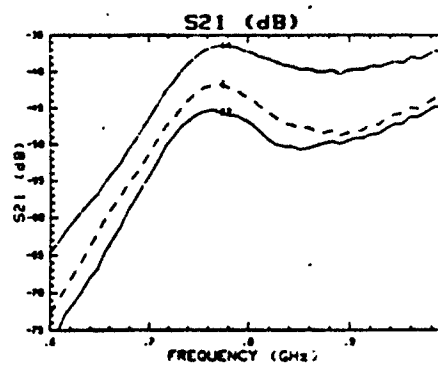
a) Sensor Height = 1 inch



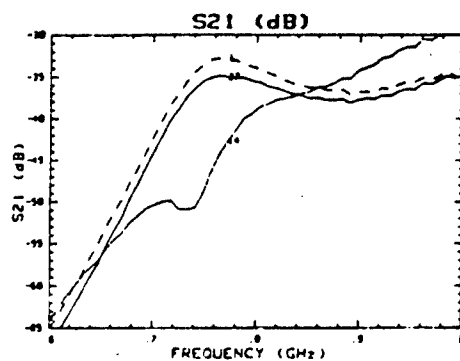
b) Sensor Height = 2 inches



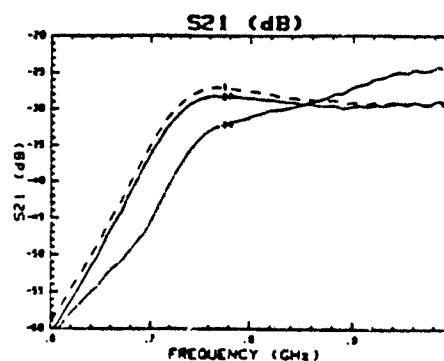
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

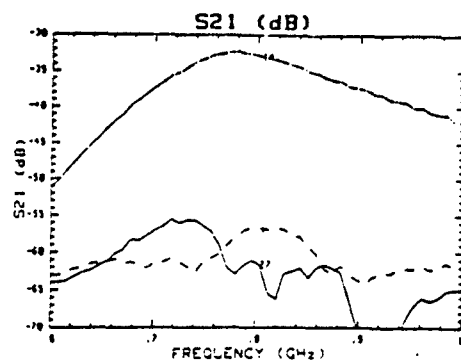


e) Sensor Height = 5 inches

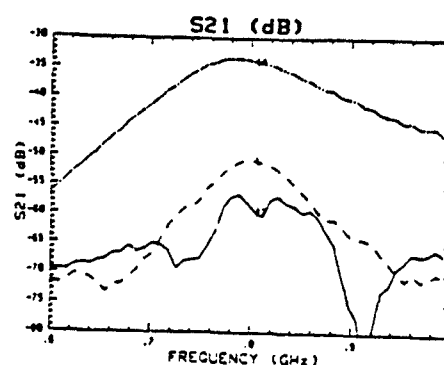


f) Sensor Height = 6 inches

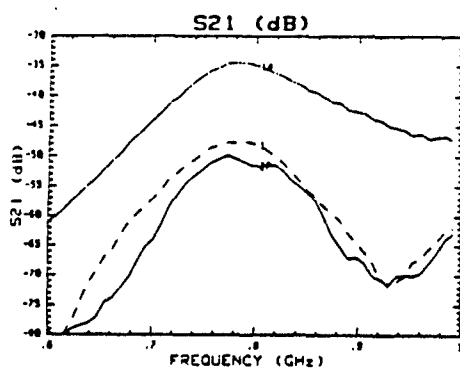
Figure 15. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. A nylon block ($12 \times 12 \times 3$ inches) is buried flush with the surface so that the broadband sensor head is centered directly over the nylon block at position 14. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil



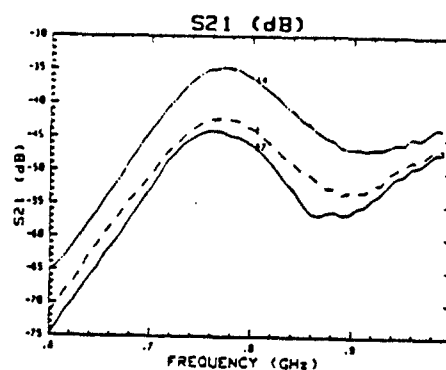
a) Sensor Height = 1 inch



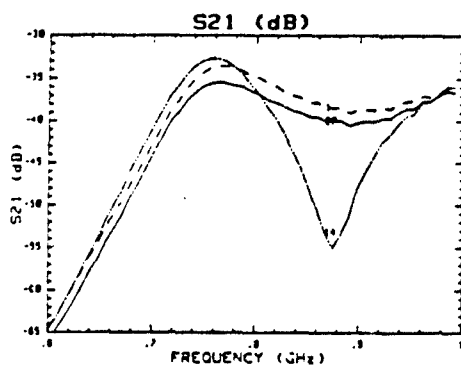
b) Sensor Height = 2 inches



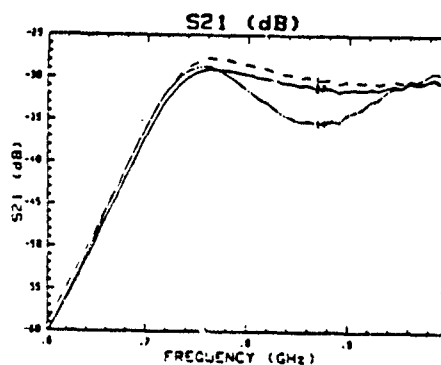
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

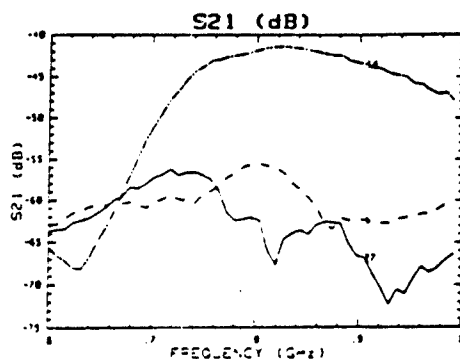


e) Sensor Height = 5 inches

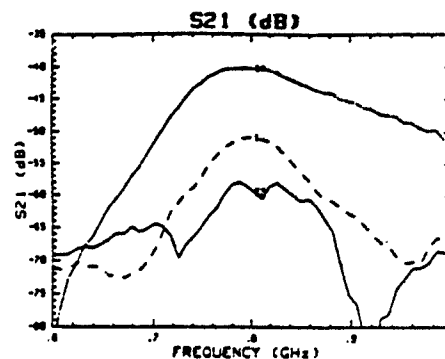


f) Sensor Height = 6 inches

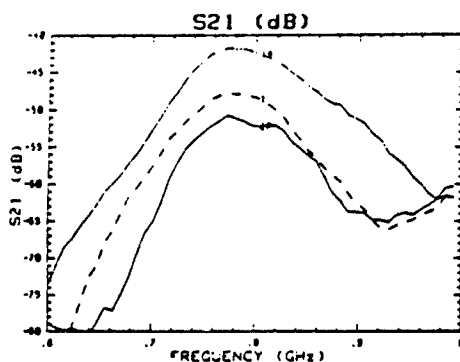
Figure 16. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. A nylon block (12 x 12 x 3 inches) is buried 3 inches below the soil surface so that the broadband sensor head is centered directly over the nylon block at position 14. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil.



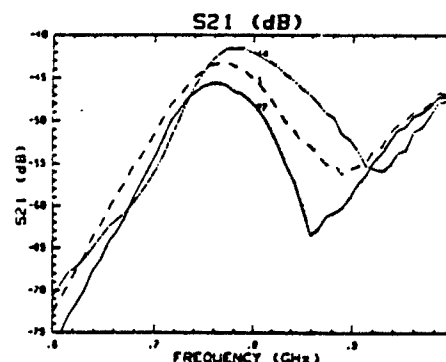
a) Sensor Height = 1 inch



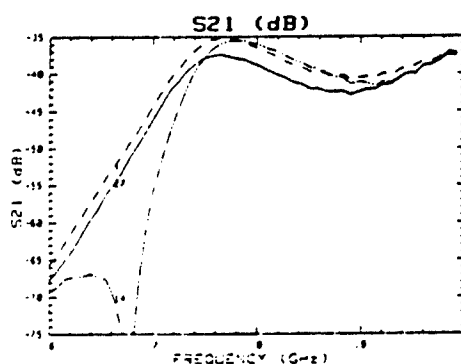
b) Sensor Height = 2 inches



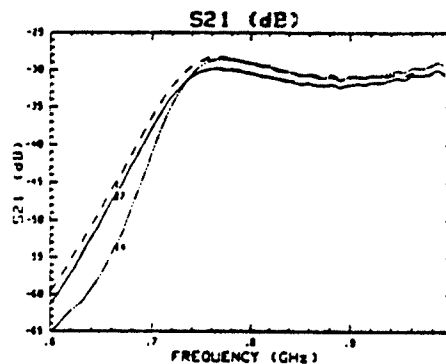
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

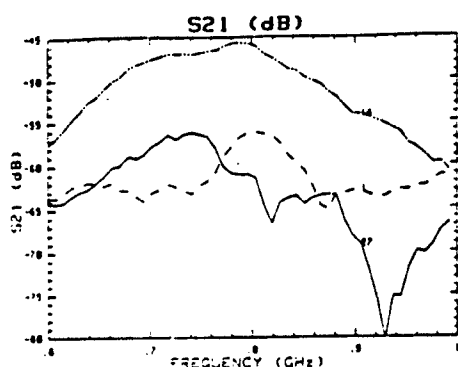


e) Sensor Height = 5 inches

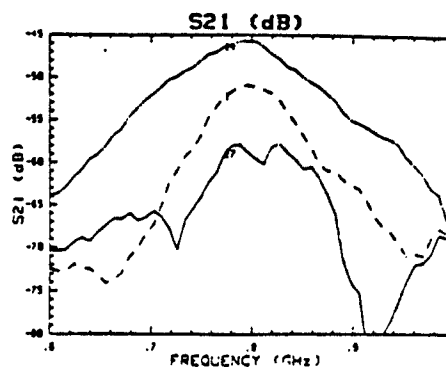


f) Sensor Height = 6 inches

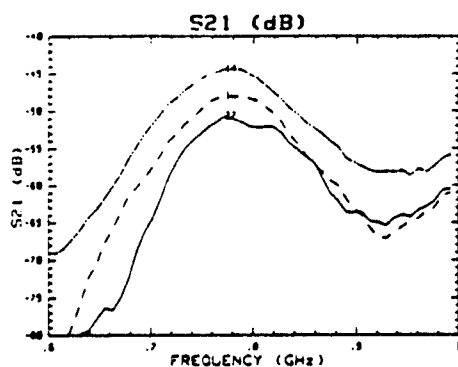
Figure 17. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. A nylon block (12 x 12 x 3 inches) is buried 6 inches below the soil surface so that the broadband sensor head is centered directly over the nylon block at position 14. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil



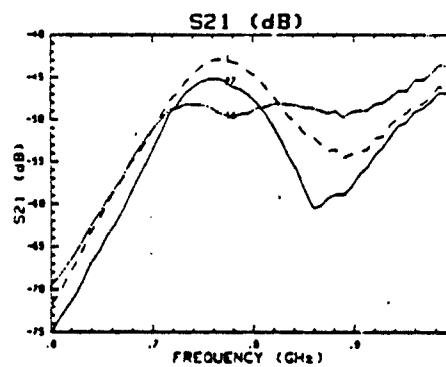
a) Sensor Height = 1 inch



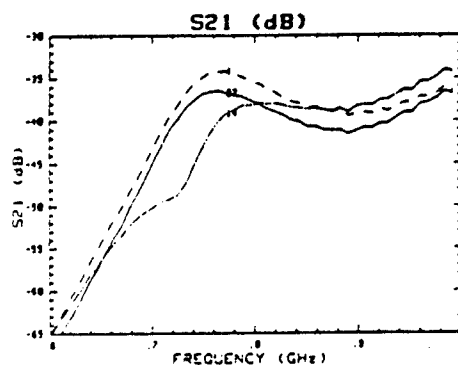
b) Sensor Height = 2 inches



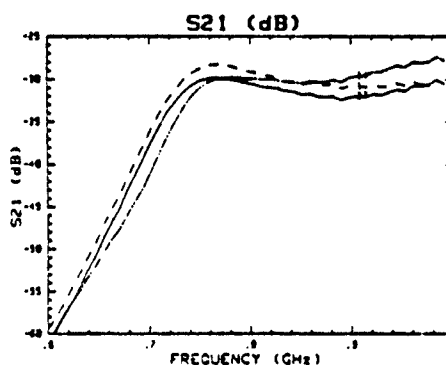
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

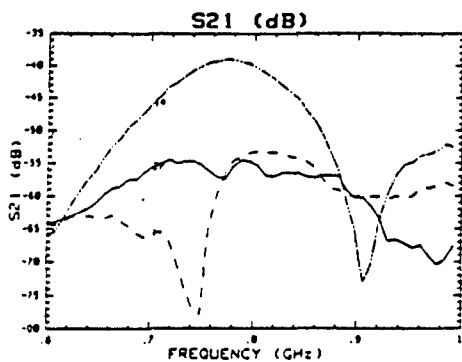


e) Sensor Height = 5 inches

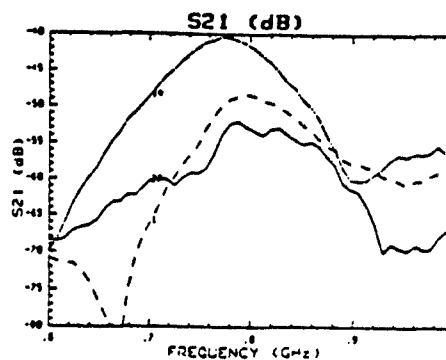


f) Sensor Height = 6 inches

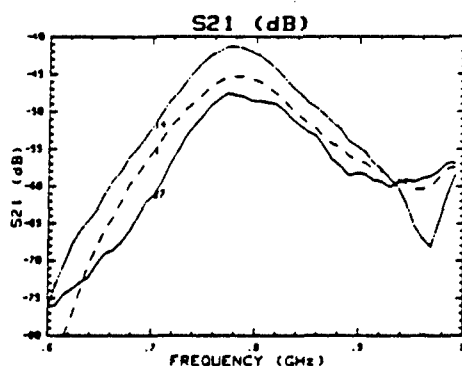
Figure 18. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. A nylon block (12 x 12 x 3 inches) is buried 9 inches below the soil surface so that the broadband sensor head is centered directly over the nylon block at position 14. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil



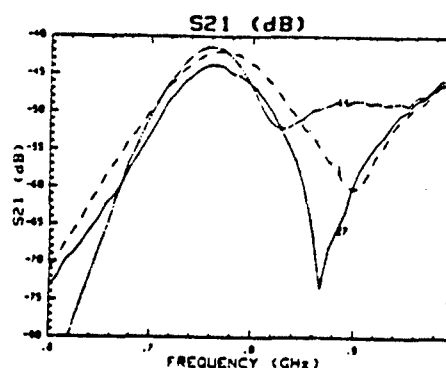
a) Sensor Height = 1 inch



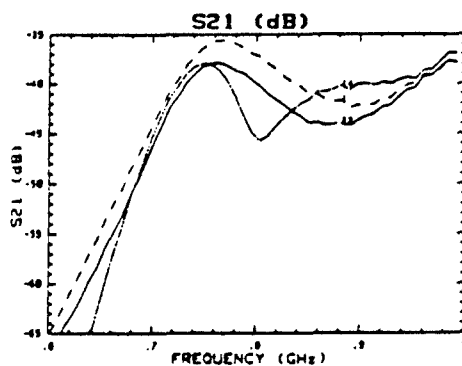
b) Sensor Height = 2 inches



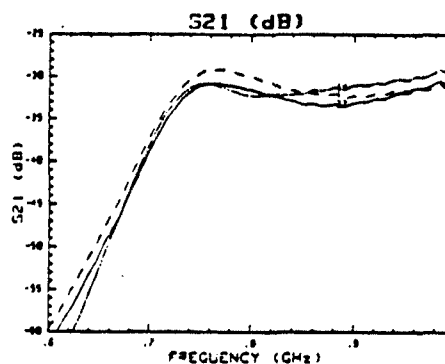
c) Sensor Height = 3 inches



d) Sensor Height = 4 inches

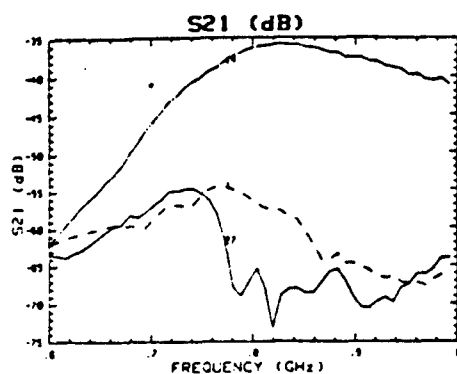


e) Sensor Height = 5 inches

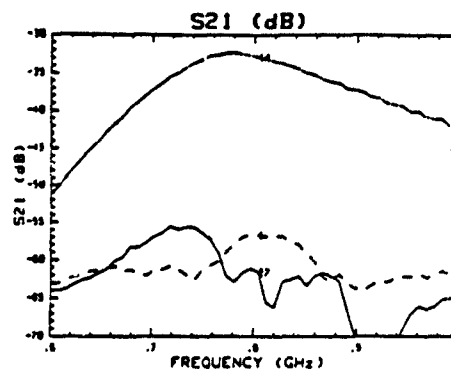


f) Sensor Height = 6 inches

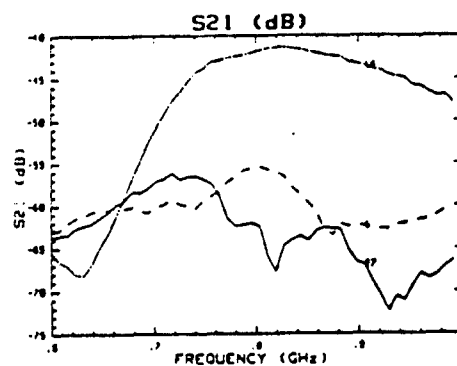
Figure 19. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. A nylon block (12 x 12 x 3 inches) is buried 12 inches below the soil surface so that the broadband sensor head is centered directly over the nylon block at position 14. The broadband sensor is: a) 1 inch; b) 2 inches; c) 3 inches; d) 4 inches; e) 5 inches; f) 6 inches above the soil



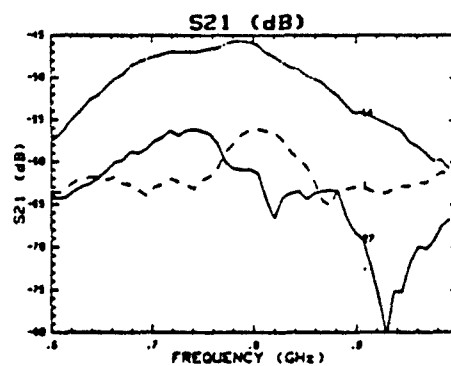
a) Anomaly Depth = Flush



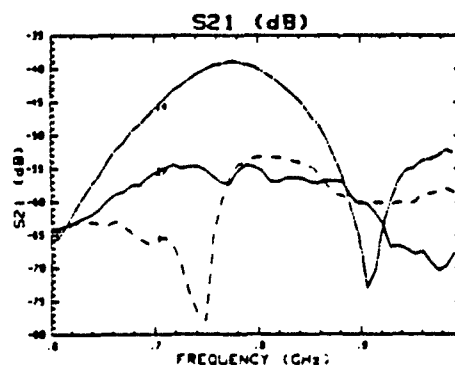
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

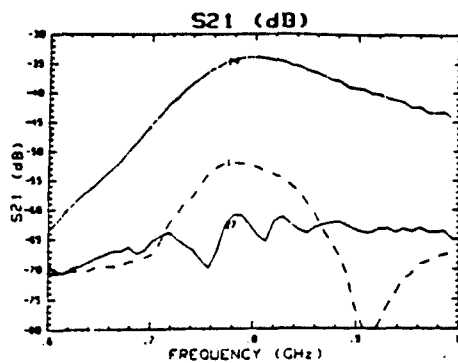


d) Anomaly Depth = 9 inches

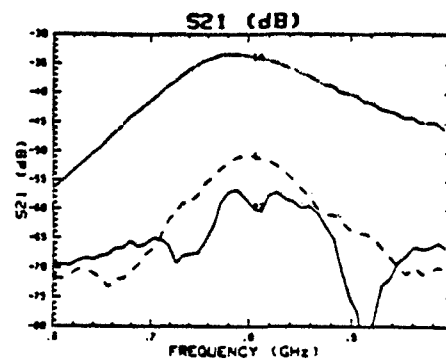


e) Anomaly Depth = 12 inches

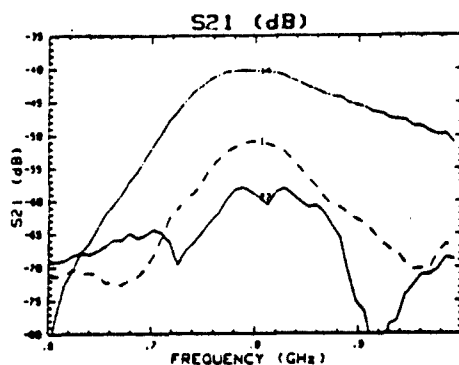
Figure 20. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 1 inch above the soil. A nylon block (12 x 12 x 3 inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



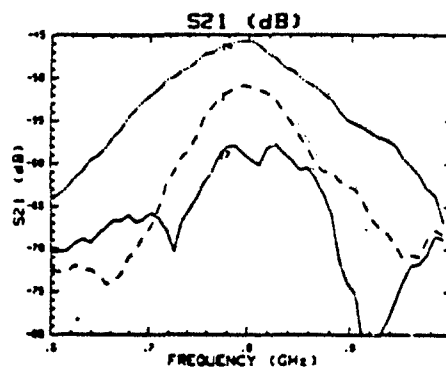
a) Anomaly Depth = Flush



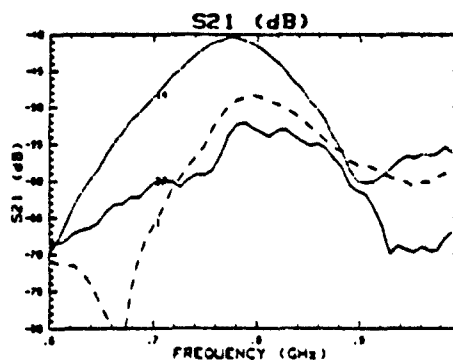
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

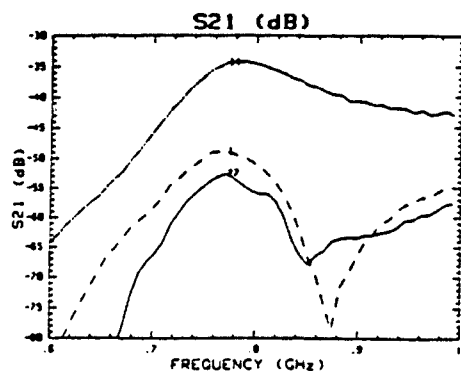


d) Anomaly Depth = 9 inches

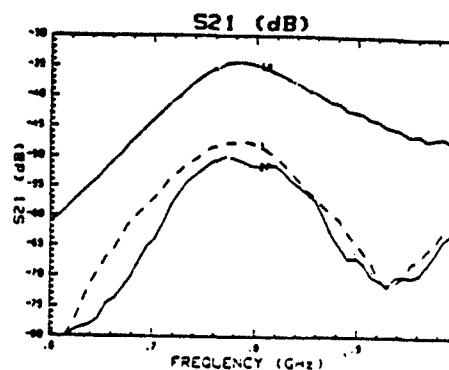


e) Anomaly Depth = 12 inches

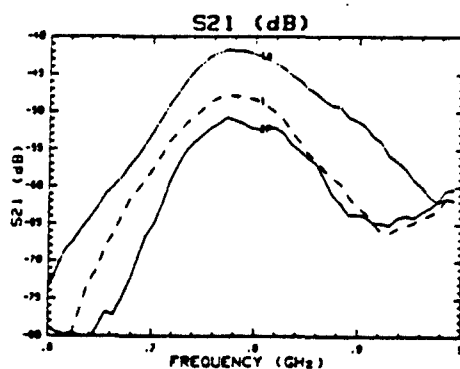
Figure 21. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 2 inches above the soil. A nylon block (12 x 12 x 3 inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



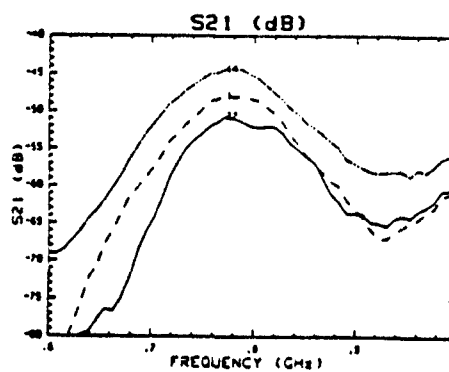
a) Anomaly Depth = Flush



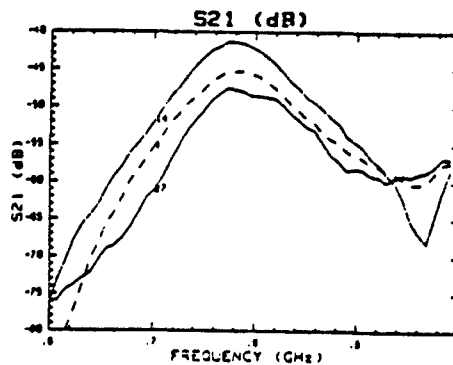
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

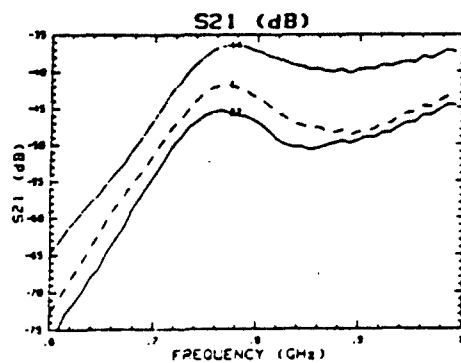


d) Anomaly Depth = 9 inches

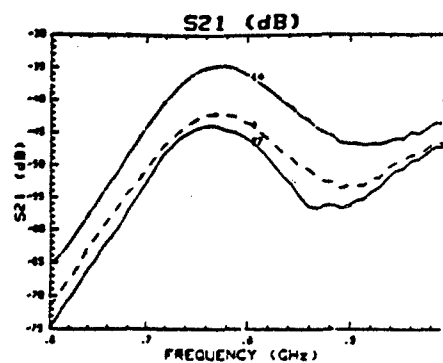


e) Anomaly Depth = 12 inches

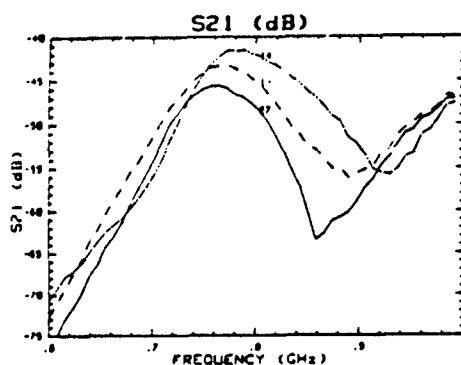
Figure 22. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 3 inches above the soil. A nylon block ($12 \times 12 \times 3$ inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



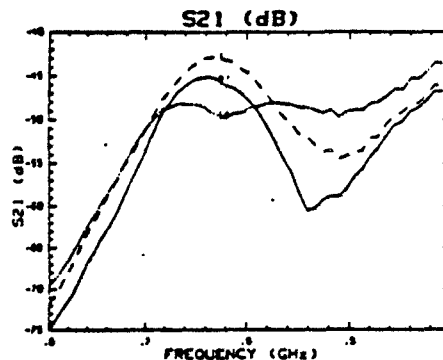
a) Anomaly Depth = Flush



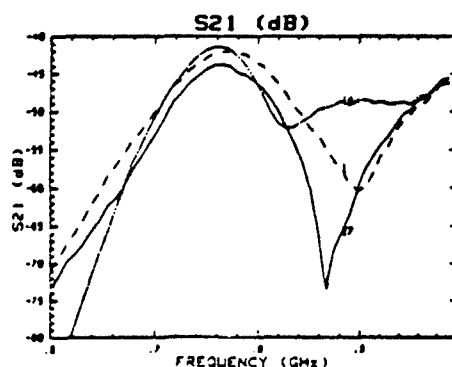
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

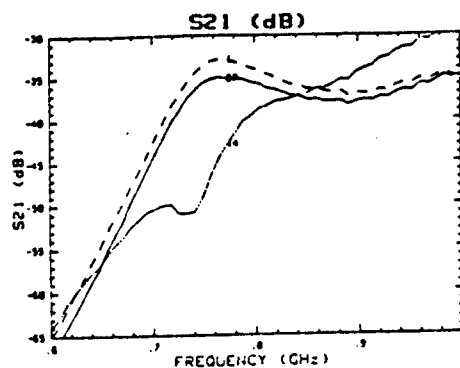


d) Anomaly Depth = 9 inches

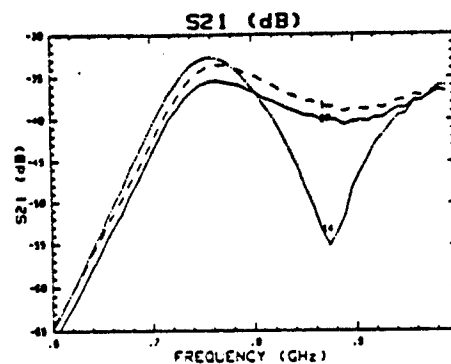


e) Anomaly Depth = 12 inches

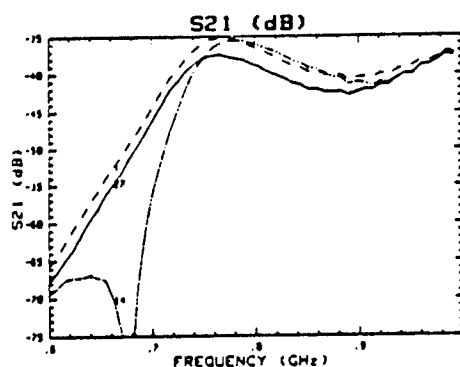
Figure 23. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 4 inches above the soil. A nylon block ($12 \times 12 \times 3$ inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



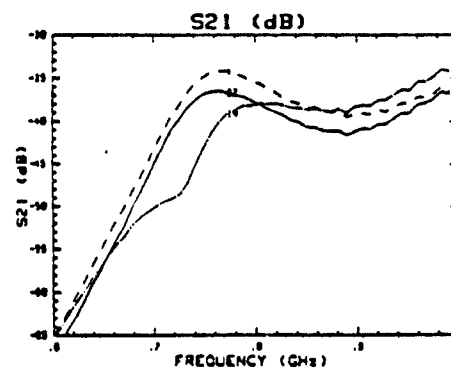
a) Anomaly Depth = Flush



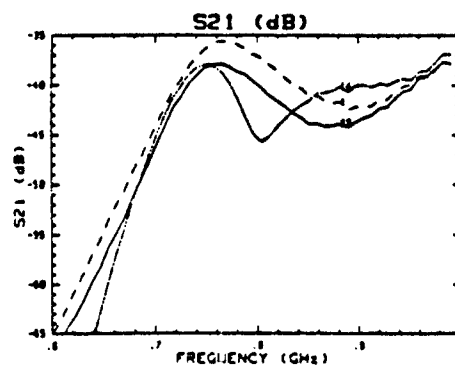
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

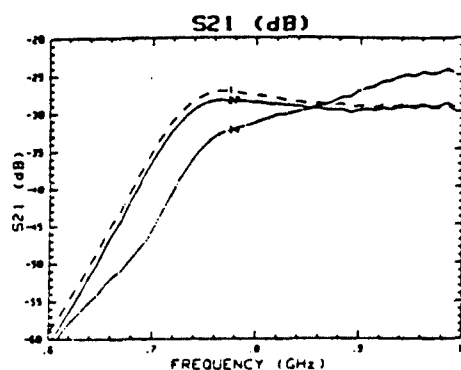


d) Anomaly Depth = 9 inches

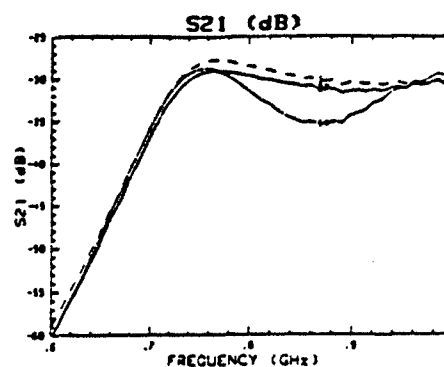


e) Anomaly Depth = 12 inches

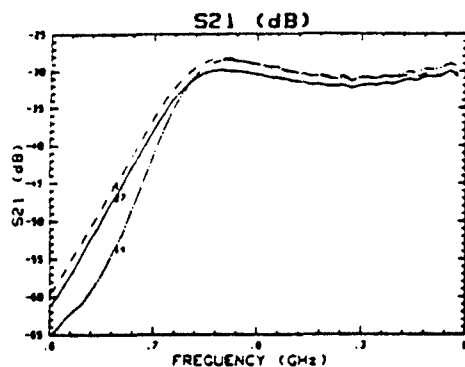
Figure 24. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curves 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 5 inches above the soil. A nylon block ($12 \times 12 \times 3$ inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



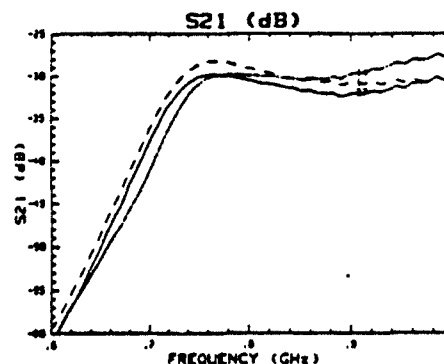
a) Anomaly Depth = Flush



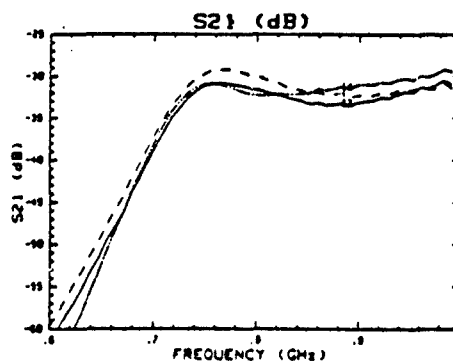
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

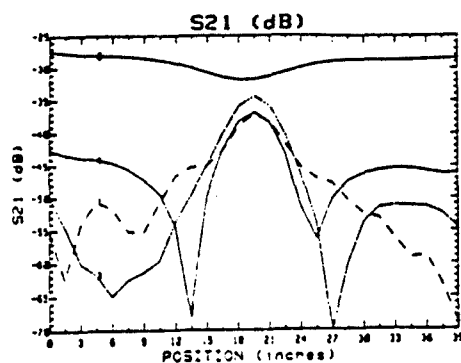


d) Anomaly Depth = 9 inches

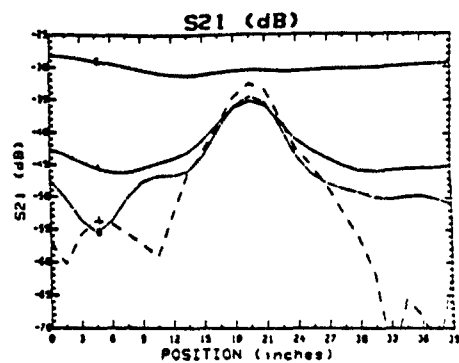


e) Anomaly Depth = 12 inches

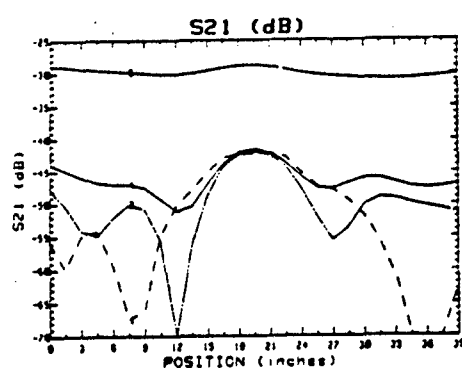
Figure 25. Measurement of transmission coefficient (S_{21}) as a function of frequency over dry, loamy soil. In each figure, curved 1, 14, and 27 correspond, respectively, to the sensor head at the far left, center, and far right of a 39-inch horizontal scan. The broadband sensor is 6 inches above the soil. A nylon block (12 x 12 x 3 inches) is buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the soil surface so that the broadband sensor is centered directly over the nylon block at position 14



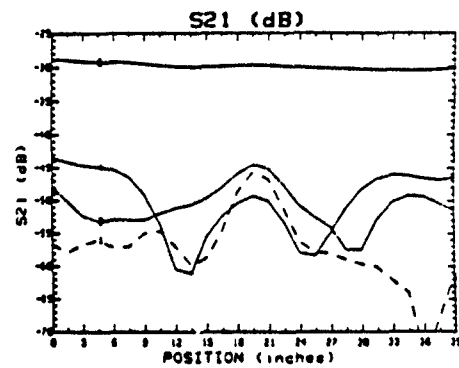
a) Anomaly Depth = Flush



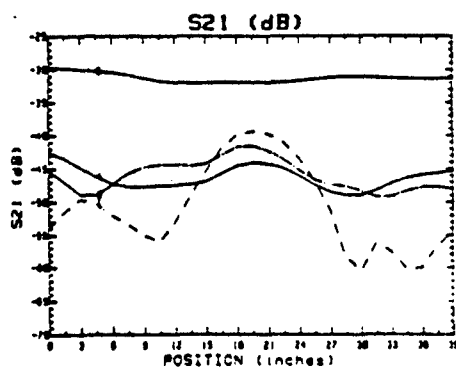
b) Anomaly Depth = 3 inches



c) Anomaly Depth = 6 inches

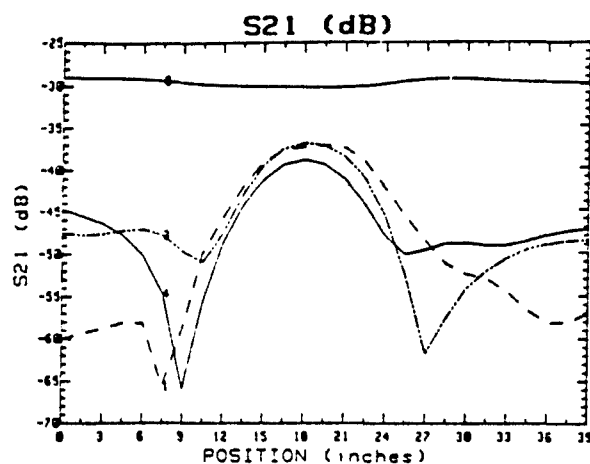


d) Anomaly Depth = 9 inches

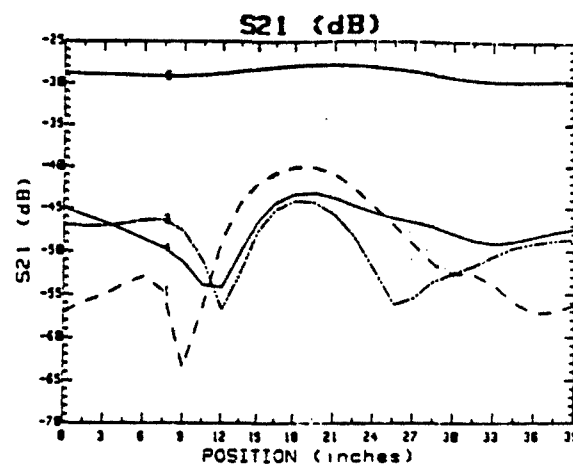


e) Anomaly Depth = 12 inches

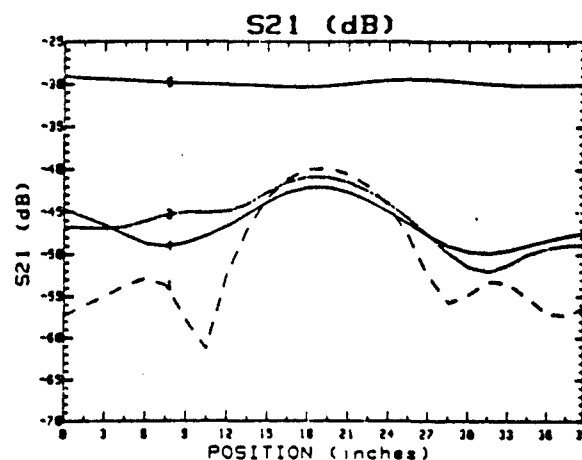
Figure 26. Measurement of transmission coefficient (S_{21}) as a function of position for various sensor heights (1, 3, 4, and 6 inches as indicated) as the broadband sensor head is scanned over a nylon block (12 x 12 x 3 inches) buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the surface of dry, loamy soil. The transmission coefficient is measured at 796 MHz which is nearly resonant frequency of the broadband dipole. The receiving dipole passes over the nylon block first



a) Anomaly Depth = Flush

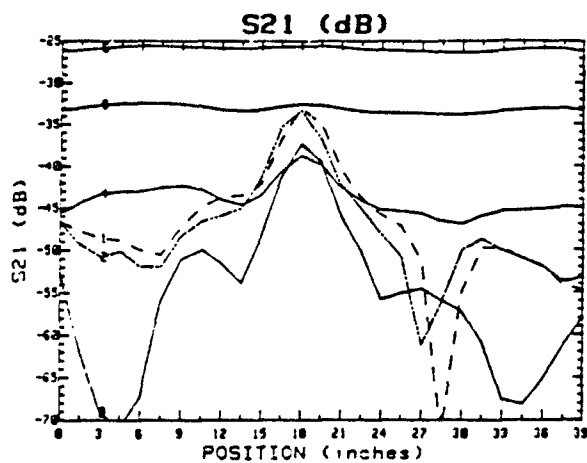


b) Anomaly Depth = 6 inches

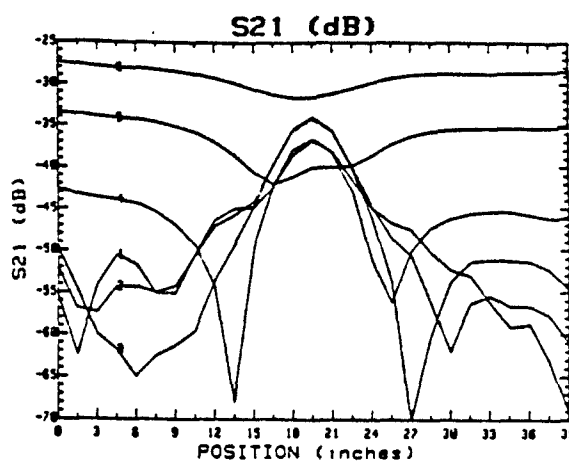


c) Anomaly Depth = 12 inches

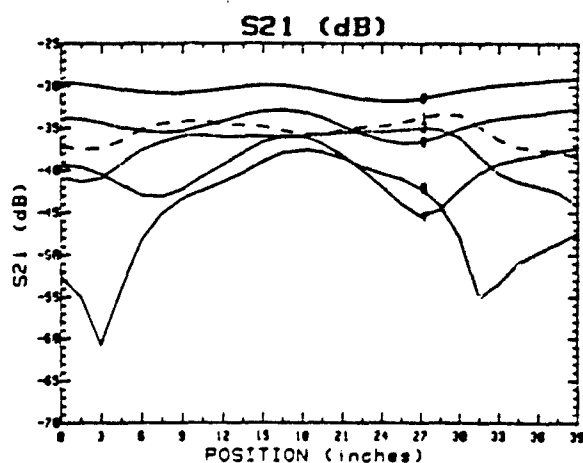
Figure 27. Measurement of transmission coefficient (S_{21}) as a function of position for various sensor heights (1, 3, 4, and 6 inches as indicated) as the broadband sensor head is scanned over a nylon block (12 x 12 x 3 inches) buried: a) flush; b) 3 inches; c) 6 inches; d) 9 inches; e) 12 inches with/below the surface of dry, loamy soil. The transmission coefficient is measured at 796 MHz which is nearly resonant frequency of the broadband dipoles. The sensor head passes oriented so that the transmit and receive dipoles are parallel to the scan direction



a) Frequency = 1 GHz

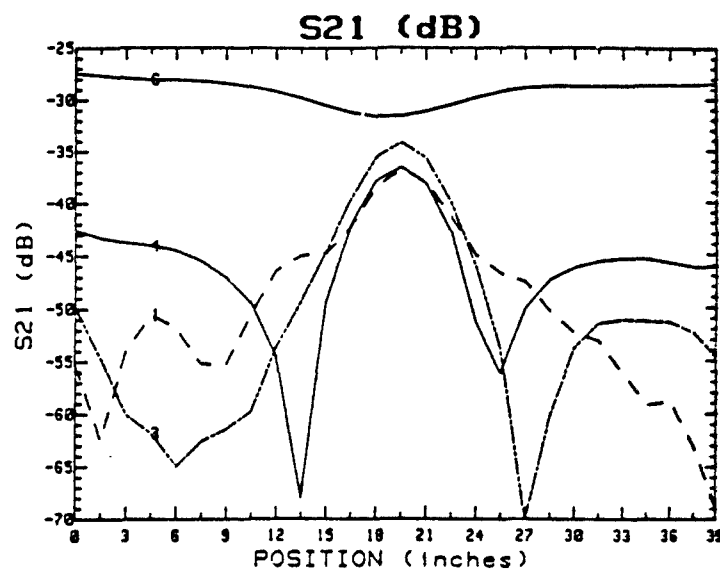


b) Frequency = 796 MHz

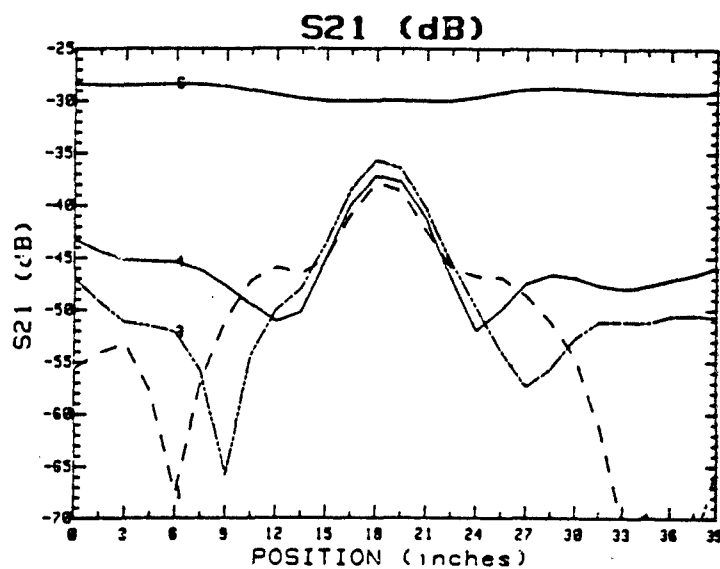


c) Frequency = 496 MHz

Figure 28. Measurement of transmission coefficient (S_{21}) as a function of position for various sensor heights (1, 3, 4, and 6 inches as indicated) as the broadband sensor head is scanned over a nylon block (12 x 12 x 3 inches) buried flush with the surface of dry, loamy soil. The receiving dipole passes over the nylon block first. The transmission coefficient is measured near the resonant frequency of the broadband dipoles at: a) 1 GHz; b) 796 MHz; c) 496 MHz

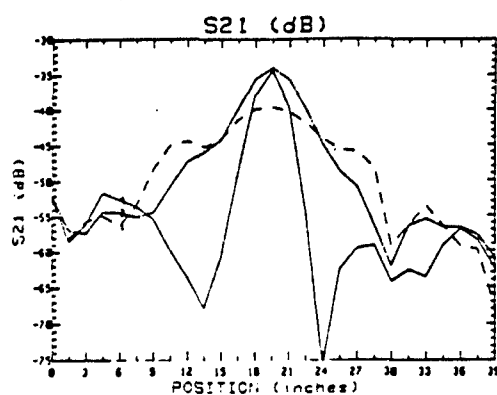


a) Broadband Dipole Sensor Head

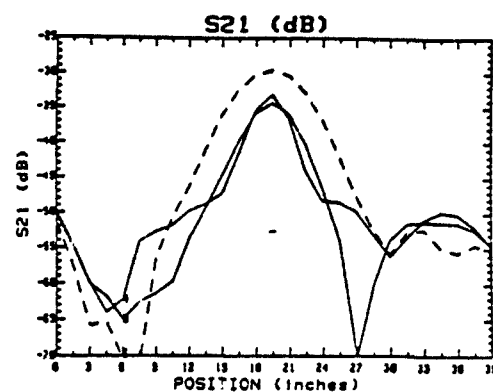


b) Printed Circuit (PC) Dipole Sensor Head

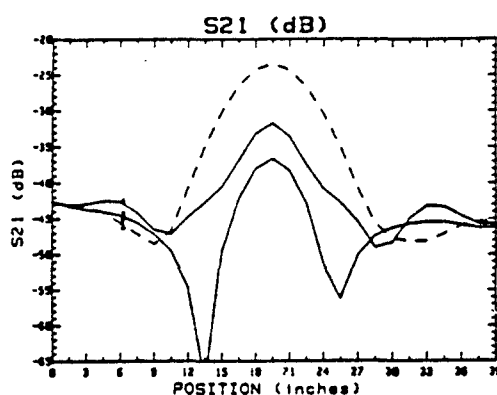
Figure 29. Measurement of transmission coefficient (S_{21}) as a function of position for various sensor heights (1, 3, 4, and 6 inches as indicated) as the: a) broadband dipole; b) printed circuit (PC) dipole sensor head is scanned over a nylon block (12 x 12 x 3 inches) buried flush with the surface of dry, loamy soil. The transmission coefficient is measured at 796 MHz which is near the resonant frequency of the broadband and PC dipoles. In each case, the receiving dipole passes over the nylon block first



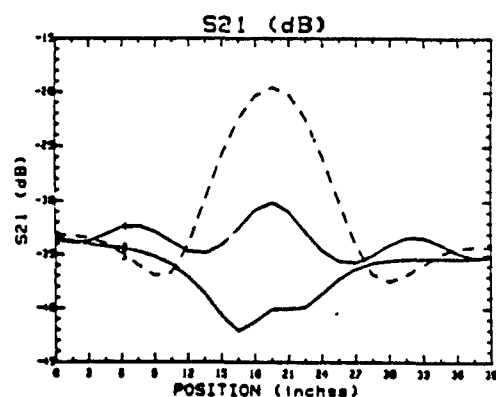
a) Sensor Height = 2 inch



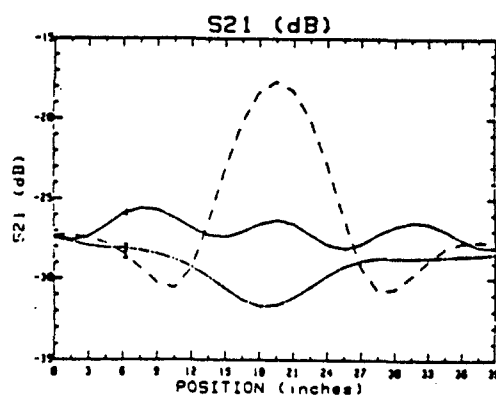
b) Sensor Height = 3 inches



c) Sensor Height = 4 inches



d) Sensor Height = 5 inches



e) Sensor Height = 6 inches

Figure 30. Measurement of transmission coefficient (S_{21}) as a function of position for various anomalies, 1 - styrofoam, 3 - nylon, 4 - water, buried flush with the surface of dry loamy soil. The transmission coefficient is measured 796 MHz which is near the resonant frequency of the broadband dipoles. In each case, the receiving dipole of the sensor passes over the anomaly first. The sensor head is: a) 2 inches; b) 3 inches; c) 4 inches; d) 5 inches; e) 6 inches above the soil surface

APPENDIX B
COMPUTER CONTROL/DATA
COLLECTION SOFTWARE

```

10  OPTION BASE 1
20  PRINTER IS 1
30  ASSIGN #MULT TO 723
40  DIM D(1:51,1:1)
50  INTEGER Hd,Lgth
60  KEY LABELS OFF
70  CLEAR SCREEN
80  INPUT "MOVE CART BACKWARDS, OR FORWARDS, OR LEAVE STATIONARY (B/F/S), Move:"
90  MoveFlag=0
100 IF Move="B" OR Move="F" OR Move="S" THEN 190
110 CLEAR SCREEN
120 PRINT "INPUT ERROR."
130 PRINT "TRY AGAIN! (Y/N)"
140 INPUT Response2
150 IF Response2="Y" THEN 80
160 CLEAR SCREEN
170 PRINT "PROGRAM DISCONTINUED."
180 STOP
190 IF Move="B" THEN GOSUB Backward
200 IF MoveFlag=1 THEN 30
210 IF Move="F" THEN GOSUB Forward
220 IF MoveFlag=1 THEN 30
230 IF Move="S" THEN 240
240 INPUT "MOVE ANTENNA TO RIGHT OR LEFT (R/L), Answer:"
250 IF Answer="R" OR Answer="L" THEN 260
260 PRINT "INPUT ERROR."
270 PRINT "TRY AGAIN! (Y/N)"
280 INPUT Response3
290 IF Response3="Y" THEN GOTO 240
300 CLEAR SCREEN
310 PRINT "PROGRAM DISCONTINUED."
320 STOP
330 IF Answer="R" THEN 370
340 MoveFlag=1
350 GOSUB Rightant
360 MoveFlag=0
370 INPUT "IS THE WAVE NOISE AT THE LEFT STOP? (Y/N), Answer:"
380 IF Answer="Y" OR Answer="L" THEN 470
390 PRINT "INPUT ERROR."
400 PRINT "TRY AGAIN! (Y/N)"
410 INPUT Response4
420 CLEAR SCREEN
430 IF Response4="Y" THEN GOTO 370
440 CLEAR SCREEN
450 PRINT "PROGRAM DISCONTINUED."
460 STOP
470 IF Answer="Y" THEN 490
480 GOSUB Leftant
490 Flag=0
500 ABORT
510 OUTPUT 710;"POLAR:"
520 CLEAR 710
530 OUTPUT 710;"S21:"
540 OUTPUT 710;"CENT 800 MHz:"
550 OUTPUT 710;"SPAN 400 MHz:"
560 OUTPUT 710;"MARK1 700 MHz:"
570 OUTPUT 710;"PONE 20 DB:"
580 OUTPUT 710;"POIN F1:"
590 OUTPUT 710;"WREFD ON:"
600 OUTPUT 710;"NUMG10:"
610 OUTPUT 710;"MUT0:"
620 INPUT "IF CALIBRATED HIT ANY KEY TO CONTINUE.",Calgo1
630 INPUT "DISABLE PRINTER? TYPE THE LETTER C",Print

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630 IF Prnt$="0" THEN 681
640 INPUT "WHAT IS TODAY'S DATE? (MM/DD/YY)",Daysdate$
650 INPUT "WHAT WAVEGUIDE? NBS OR CUBIC: ",Waveguide$
660 INPUT "WHAT DIELECTRIC MATERIAL IS BEING TESTED? ",Dielectric$
670 INPUT "HOW DEEP IS ANOMALY BURIED? (INCHES)",Dist$
680 PRINT "IS THIS TEST AN AREA SCAN OR A LINE SCAN OR
690 PRINT "A FIXED POSITION SCAN (ASCAN/SCAN/FIXED)?"
700 INPUT Position$
710 IF Position$="ASCAN" OR Position$="SCAN" OR Position$="FIXED" THEN 800
720 CLEAR SCREEN
730 PRINT "INPUT ERROR."
740 PRINT "TRY AGAIN" (Y/N)?
750 INPUT Response$
760 CLEAR SCREEN
770 IF Response$="Y" THEN 680
780 PRINT "PROGRAM DISCONTINUED."
790 STOP
800 IF Position$="ASCAN" THEN Flag=2
810 IF Position$="FIXED" THEN
820 Flag=1
830 ELSE
840 CLEAR SCREEN
850 INPUT "WHAT IS HEIGHT OF WAVEGUIDE ABOVE GROUND? (INCHES)",Height$
860 END IF
870 CLEAR SCREEN
880 INPUT "WHAT ARE MEASUREMENT INCREMENTS? (INCHES)",Increments$
890 Increments=VAL(Increments$)
900 INPUT "HOW MANY READINGS ARE TO BE TAKEN?",Readings
910 NumIncrements$=VAL$(Readings)
920 IF Flag=2 THEN INPUT "HOW MANY INCREMENTS IS CART TO MOVE?",Scanbr
930 INPUT "NAME OF FILE?",One$
940 INPUT "READY TO COLLECT DATA? (Y/N)",Go$
950 IF Go$="Y" THEN 990
960 CLEAR SCREEN
970 DISP "PROGRAM HAS BEEN ABORTED."
980 STOP
990 IF Flag=1 THEN 1050
1000 FOR J=37 TO Scanbr
1010 Column=Readings
1020 Rowck=Jag*J
1030 Rowcheck=J/2
1040 IF Rowcheck=INT(Rowcheck) THEN Rowck=Jag*J
1050 FOR I=1 TO Readings
1060 IF Flag=0 THEN 1070
1070 FOR Z=1 TO 10
1080 ON KEY LABEL "ABORT",1 GOTO 2770
1090 NEXT Z
1100 KEY LABELS ON
1110 ASSIGN @C: TO F10;FORMAT OFF
1120 IF Flag=1 THEN
1130 INPUT "HIT ANY KEY TO PROCEED",Wait$
1140 OUTPUT F10;"NUMG10;F0RMT3;OUTPDAT1;"
1150 ELSE
1160 OUTPUT F10;"NUMG10;F0RMT3;OUTPDAT1;"
1170 END IF
1180 ENTER @C;Hdr;Lgth;Dat$;
1190 IF Flag=2 THEN
1200 IF Rowck=Jag*J THEN
1210 T$=VAL$(Column) IF ROW IS EVEN NUMBER THEN COUNT BACKWARDS
1220 ELSE
1230 Two$=VAL$(1)
1240 END IF
1250 Four$=VAL$(1)
1260 Three$=One$&"R"&Four$&"C"&Two$
1270 ELSE
1280 Two$=One$&"R"

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1300 Three$=units :Two$
1310 END IF
1320 DISP "THIS IS FILE NAME INCLUDING MEASUREMENT NUMBER: ",Three$
1330 OPENE BOUT Three$,5
1340 ASSIGN BOUT TO Three$
1350 OUTPUT @Disc@Hd@,Lgth@,Lat@
1360 IF Print$="C" THEN 1400
1370 OUTPUT "13:USER=SC PRINALL:"
1380 Stat$=Pollution
1390 IF NOT BIT(Stat$,5) THEN GOTO 1380
1400 SEND TOTAL TO CHD 9
1410 DISP PRINTING CRT (INACE FROM NETWORK ANALIZER)
1420 STATUS 7,5:HP:6
1430 IF NOT BIT(Hd$b,6) THEN GOTO 1420
1440 PRINTER IS 701
1450 FOR I=1 TO 3
1460 PRINT CHR$(10)
1470 NEXT I
1480 PRINT "FILE NAME IS: ",Three$
1490 PRINT "WAVEGUIDE IS: ",Waveguide$
1500 PRINT "DATE: ",Daysdate$
1510 IF Flag=0 THEN
1520 PRINT "WAVEGUIDE HEIGHT ABOVE GROUND IS: ",Height$, "INCHES"
1530 ELSE
1540 PRINT "WAVEGUIDE HEIGHT ABOVE GROUND IS: ",1, "INCHES"
1550 END IF
1560 PRINT "DIELECTRIC MATERIAL TESTED IS: ",Dielectric$
1570 PRINT "POSITIONING OVER TARGET IS: ",Position$
1580 PRINT "RESOLUTION OF POSITIONING IS EVERY: ",Increment$, "INCHES"
1590 (Increment$=VAL(Increment$))
1600 PRINT "NUMBER OF MEASUREMENT INCREMENTS IS: ",Mincrement$
1610 PRINT "THE DISTANCE FROM THE SOIL SURFACE TO THE TOP OF THE DIELECTRIC
      ANOMALY IS: ",Dist$, "INCHES"
1620 PRINT CHR$(12)
1630 PRINTER IS 1
1640 Column=Column+1
1650 IF Readings OR Position$="FINED" THEN 1710
1660 IF Pouchflag=1 THEN
1670 GOSUB Leftant
1680 ELSE
1690 GOSUB Rghtant
1700 END IF
1710 NEXT I
1720 IF (I MOD 6) = 0 THEN 1720
1730 INPUT "IF DISC HAS BEEN CHANGED HIT ANY KEY TO CONTINUE",Go$
1740 IF Flag=2 THEN 1750
1750 IF J-Scanner THEN 1750
1760 GOSUB Cartmov
1770 NEXT J
1780 KEY LABELS OFF
1790 Distance=Readings-1)*Mincrement$
1800 DISP
1810 PRINTER IS 1
1820 CLEAR SCREEN
1830 PRINT "LAST MEASUREMENT HAS BEEN STOPPED. PROGRAM IS DONE."
1840 PRINT
1850 IF Position$="FINED" THEN 1860
1860 PRINT "WAVEGUIDE HAS MOVED: ",Distance, "INCHES"
1870 KEY LABELS ON
1880 STOP
1890 Pghtants:
1900 IF Antflag=1 THEN
1910 OUTPUT @Unit1: OP 0.05413,7" HIGH CURRENT
1920 WAIT .3
1930 OUTPUT @Unit1: OP 0.0544,7" HIGH CURRENT

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```

1920      WAIT .2
1930      OUTPUT @Multi;"CP 6,65441,T"  FLOW CURRENT
1940      INPUT "HIT ANY KEY TO STOP",Stoptheant
1950      GOSUB Stopant
1960      RETURN
1970      ELSE
1980      WAIT 1.0
1990      OUTPUT @Multi;"OP 6,65442,T"  MED CURRENT
2000      WAIT .2
2010      OUTPUT @Multi;"OP 6,65441,T"  FLOW CURRENT
2020      WAIT .920
2030      GOSUB Stopant
2040      END IF
2050      Antflag=0
2060      RETURN
2070 Leftant:
2080      IF Forchflag=1 THEN
2090      WAIT 1.0
2100      OUTPUT @Multi;"OP 6,65442,T"  MED CURRENT
2110      WAIT .2
2120      OUTPUT @Multi;"OP 6,65443,T"  FLOW CURRENT
2130      WAIT .920
2140      GOSUB Stopant
2150      ELSE
2160      INPUT "HOW FAR FROM LEFT STOP IS WAVEGUIDE (INCHES)?",Inches
2170      Accumtime=Inches*1.5*1.13
2180      OUTPUT @Multi;"OP 6,65445,T"  HIGH CURRENT
2190      WAIT .3
2200      OUTPUT @Multi;"OP 6,65442,T"  MED CURRENT
2210      WAIT .2
2220      OUTPUT @Multi;"OP 6,65443,T"  FLOW CURRENT
2230      WAIT Accumtime
2240      GOSUB Stopant
2250      END IF
2260      RETURN
2270 Stopant:
2280      OUTPUT @Multi;"OP 6,65534,T"
2290      RETURN
2300 Stopcart:
2310      Refreshmenu=1
2320      OUTPUT 723;"CP 11,65526,T"
2330      OUTPUT 723;"OP 11,65522,T"
2340      DISP "CART STOPPED"
2350      RETURN
2360 Forward:
2370      Moveflag=0
2380      FOR I=1 TO 3
2390      ON KEY I LABEL " STOP ",2 GOTO 2470
2400      NEXT I
2410      KEY LABELS ON
2420      DISP "CART MOVING FORWARD"
2430      OUTPUT 723;"OP 11,65533,T"
2440      OUTPUT 723;"WD 8.1,4000T,WD 14.2,4000T"
2450      OUTPUT 723;"OP 2,5,14,5T"
2460      GOTO 2450
2470      GOSUB Stopcart
2480      DISP
2490      INPUT "MOVE CART SOME MORE? Y/N",Answer3
2500      IF Answer3="Y" THEN Moveflag=1
2510      RETURN
2520 Backward:
2530      Moveflag=0
2540      FOR I=1 TO 3
2550      ON KEY I LABEL " STOP ",2 GOTO 2670
2560      NEXT I
2570      KEY LABELS ON

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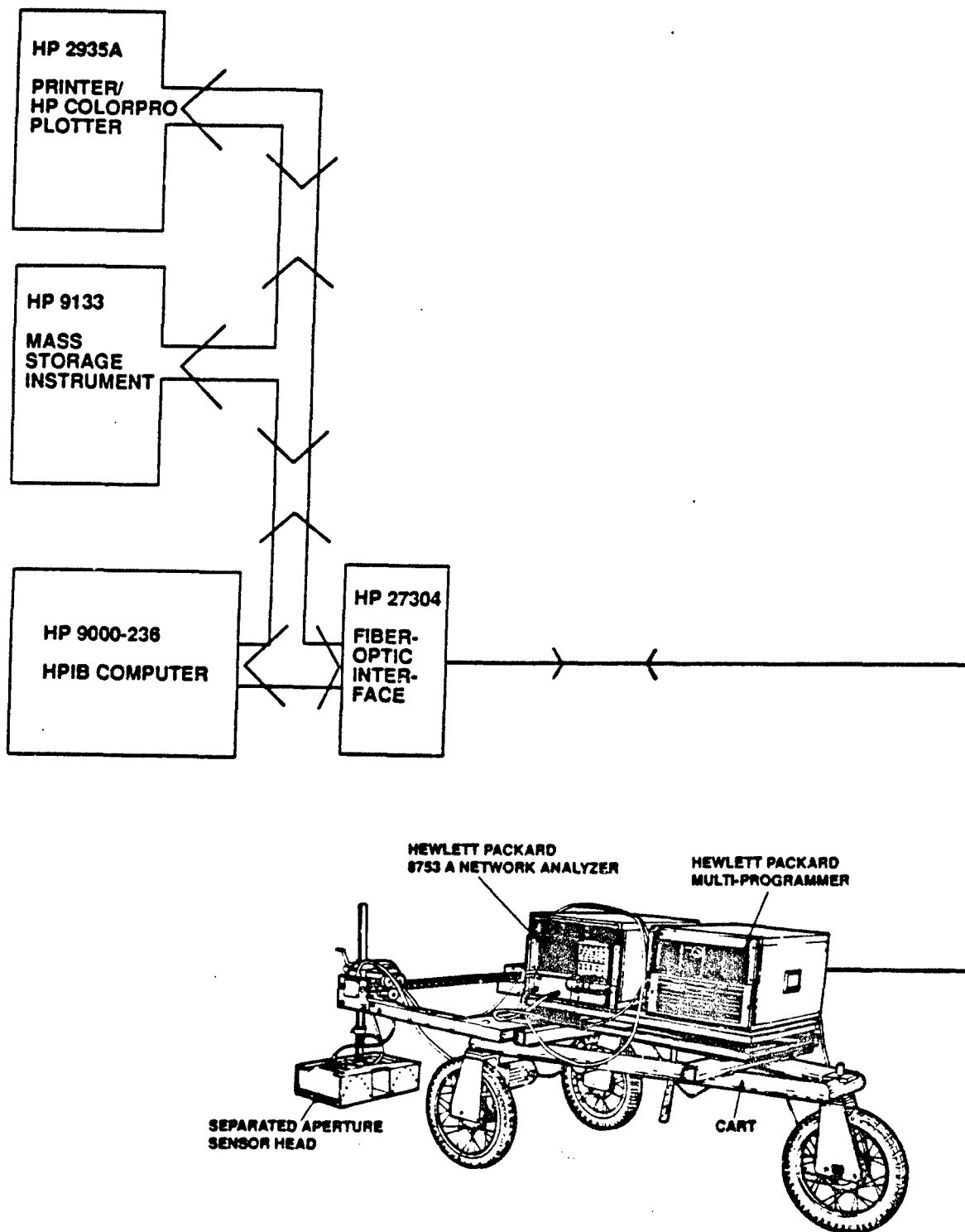
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2590      2590      2590      2590      2590      2590      2590      2590      2590      2590
2600      OUTPUT 723;"OP 11,65519,T"
2610      OUTPUT 723;"WC 8.2,4000T,WC 14.2,4000T"
2620      OUTPUT 723;"OP 8,5,14,5,T"
2630      GOTO 2610
2640      GOSUB Stopcar
2650      DISP
2660      INPUT "MOVE CART SOME MORE? (Y/N) ",Answer3:
2670      IF Answer3="Y" THEN MoveFlag=1
2680      RETURN
2690      Cartmov:
2700      INTEGER Scansiz,Scander
2710      Cart_pulse=.003
2720      Scansiz=64
2730      Scander=32
2740      Scanspc=ROUND(Scansiz/Scander,3)
2750      Movecart(Scanspc,Cart_pulse)
2760      WAIT 1.5
2770      RETURN
2780      KEY LABELS OFF
2790      GOSUB Stopant
2800      DISP "PROGRAM ABORTED."
2810      KEY LABELS ON
2820      END
2830      Movcart: SUB Movecart(REAL Distance,Rate)
2840      IF Distance>0 THEN
2850      OUTPUT 723;"OP 11,65537,T"
2860      ELSE
2870      OUTPUT 723;"OP 11,65519,T"
2880      END IF
2890      OUTPUT 723;"WC 8.2,4000T,WC 14.2,4000T"
2900      FOR X=0 TO ABS(Distance) STEP Rate*5
2910      OUTPUT 723;"OP 8,5,14,5,T"
2920      NEXT X
2930      OUTPUT 723;"OP 11,65520,T"
2940      SUBEND

```

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Block Diagram of Data Collection System

APPENDIX C

PLOTting SOFTWARE

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190 INPUT G$ : LET USER VIEW MESSAGES
200 ON KEY GOTO 1350 : PROVIDE EXIT
210 OUTPUT 2 USING "0,K" : CLEAR SCREEN FOR GRAPH
220 GINIT : INITIALIZE VARIOUS GRAPHICS PARAMETERS
230 IF Iplt="N" THEN
240 PLOTTER IS CRT,"INTERNAL" : USE THE INTERNAL SCREEN
250 ELSE
260 PLOTTER IS "HPGL" : USE THE COLORPRO HP PLOTTER
270 END IF
280 GRAPHICS ON : TURN ON THE GRAPHICS SCREEN
290 LOGO 0 : REFERENCE POINT : CENTER OF TOP OF LABEL
300 X_gdu_max=100*MAX(1,RATIO) : DETERMINE HOW MANY CDSX WIDE THE SCREEN IS
310 Y_gdu_max=100*MAX(1,1/RATIO) : DETERMINE HOW MANY CDSX HIGH THE SCREEN IS
320 FOR I=1.7 TO 1.3 STEP .1 : OFFSET OF X FROM STARTING POINT
330 MOVE X_gdu_max/2.2-I,.35*Y_gdu_max : MOVE TO ABOUT MIDDLE OF TOP OF SCREEN
340 LABEL "Title" : WRITE TITLE OF PLOT
350 NEXT I : NEXT POSITION FOR TITLE
360 DEG : ANGULAR MODE IS DEGREES (USED IN LDIR)
370 LDIR 90 : SPECIFY VERTICAL LABELS
380 CSIZE 3.5 : SPECIFY SMALLER CHARACTERS
390 MOVE .13*X_gdu_max,.13*Y_gdu_max : MOVE TO CENTER OF LEFT EDGE OF SCREEN
400 LABEL "Labels" : WRITE Y-AXIS LABEL
410 LOGO 4 : REFERENCE POINT: CENTER OF BOTTOM OF LABEL
420 LDIR 0 : HORIZONTAL LABELS AGAIN
430 MOVE X_gdu_max/2.2-.13*Y_gdu_max : CENTER OF SCREEN; Y: ABOVE KEY LABELS
440 LABEL "Labels" : WRITE X-AXIS LABEL
450 VIEWPORT .20*X_gdu_max,.20*Y_gdu_max,.8*X_gdu_max,.8*Y_gdu_max
460 : DEFINE SUBSET OF SCREEN AREA
470 WINDOW Xmin,max,Ymin,max : ANISOTROPIC SCALING: LEFT/RIGHT-BOTTOM/TOP
480 AES Xinc,Yinc,Xmin,Ymin,Xmt,Ymt,3 : DRAW AXES INTERSECTING AT LOWER LEFT
490 HES Xinc,Yinc,Xmax,Ymax,Xmt,Ymt,3 : DRAW AXES INTERSECTING AT UPPER RIGHT
500 GRID Xhgl,Xmin,Ymin,1,1 : DRAW GRID WITH NO MINOR TICKS
510 CLIP OFF : SO LABELS CAN BE OUTSIDE VIEWPORT LIMITS
520 CSIZE 2.5,.5 : SMALLER CHARTS FOR AXIS LABELLING
530 LOGO 0 : REF PT: TOP CENTER
540 Xmax=Xmax-Xhgl
550 Xmax=Xmax.
560 FOR X=imin TO xmax STEP Xhgl : EVERY XHGL UNITS
570 MOVE X,Ymin-.01*ABS(Xmin) : A SMIDGON BELOW X-AXIS
580 LABEL USING "0,K" : A : COMPACT; NO CR/LF
590 NEXT X : LET SEQUENS
600 LOGO 2 : REF. PT: RIGHT CENTER
610 Ymin=.6
620 WINDOW Xmin,max,Ymin,max
630 Ymax=Ymax-Yhgl
640 Ymax=Ymax.
650 FOR Y=imin TO imax STEP Yhgl : EVERY YHGL UNITS
660 MOVE Xmin-.01*ABS(Xmin),Y : A SMIDGON LEFT OF Y-AXIS
670 LABEL USING "0,K" : A : COMPACT; NO CR/LF
680 NEXT Y : LET SEQUENS
690 Ymin=0.
700 WINDOW Xmin,max,Ymin,max
710 CLIP ON
720 PENUP : LABEL STATEMENTS LEAVES THE PEN DOWN
730 FOR K=1 TO N
740 LINE TYPE Ltype
750 K=0
760 FOR X=xdatamin TO xdatamax STEP Xdelta : POINTS TO BE PLOTTED.
770 K=K+1
780 IF K IS THEN PLOT Y,Hy,K,K : SET A DATA POINT AND PLOT IT AGAINST X
790 NEXT X
800 LOGO 0
810 K=0
820 FOR X=xdatamin TO xdatamax STEP Xdelta
830 K=K+1
840 IF Hy=K*Ydelta AND X=K*Xdelta THEN

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1250 LINE TYPE 1
1260 MOVE A,MYPRG1,001
1270 LABEL Mes          Labels for each line (see line 93)
1280 Mes=Mes+1
1290 END IF
1300 NEXT X
1310 PERIOD
1320 UNIT 2
1330 NEXT Y
1340 GOTO 1340
1350 GRAPH-ICS OFF
1360 OUTPUT 2 USING "*,K" (0)
1370 PRINT "THE DEMO IS COMPLETE. YOU CAN USE THE BASIC SYSTEM AGAIN."
1380 END      FINIS

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